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The factors of motion sickness – Developing Janitor Run, the virtual reality scooter game

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ABSTRACT

This bachelor's thesis presents a study on the effects of motion sickness, vection and nausea in the context of virtual reality environments through a developed virtual reality kick scooting game called Janitor Run VR. The main research problems to be studied were which of the many aspects of virtual reality games induce motion sickness and nausea, and how these negative effects can be mitigated or eliminated. The methods used were twofold. First, a brief literature review was conducted on the history, best practices and common problems on virtual reality. Then, a two-phased evaluation was conducted, where participants were asked to try the developed game and give feedback on the studied negative effects through an interview and a questionnaire. The results gathered from 12 different participants on each evaluation phase seem to indicate, that there is a link between the perceived discomfort and motion sickness with a more realistic motion scheme and the use of sound effects and background music.

Keywords: Virtual reality, vection, cybersickness, immersion, game, motion sickness, kick scooter, scooter, custom controller, janitor run

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TIIVISTELMÄ

Tämä kandidaatintyö tuo esille tutkimuksen matkapahoinvointiin ja vektion virtuaalitodellisuudessa kehitetyn virtuaalitodellisuuspotkulautapelin, Janitor Run VR:n, kautta. Kandidaatintyön päätutkimusongelmat käsittelevät sitä, kuinka virtuaalitodellisuuspelit saavat aikaan pahoinvointia ja kuinka niiden haitallisia vaikutuksia voidaan vähentää tai eliminoida. Tutkimuksessa käytettiin kahta tutkimusmenetelmää. Ensin suoritettiin lyhyt kirjallisuuskatsaus virtuaalitodellisuuden historiasta, parhaista käytäntötavoista sekä yleisistä ongelmista. Sen jälkeen toisena menetelmänä käytettiin kaksivaiheista evaluaatiota, joissa molemmissa kerättiin palautetta 12 osallistujilta tutkittuihin negatiivisiin vaikutuksiin haastattelun ja kyselyn avulla. Tutkimuksen tulokset näyttävät osoittavan linkin havaitun pahoinvoinnin, realistisen liikkumisen sekä äänitehosteiden ja taustamusiikin kanssa.

Avainsanat: Virtuaalitodellisuus, vektio, kyberpahoinvointi, immersio, peli, matkapahoinvointi, potkulauta, skootteri, mukautettu ohjain, janitor run

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ABBREVIATIONS

VR	Virtual Reality
FOV	Field of view
SUS	Slater-Usoh-Steed
UI	User interface
LCD	Liquid crystal display
LED	Light-Emitting Diode
SDE	Screen-door-effect
USD	United States Dollar

1. INTRODUCTION

The aim of this thesis is to continue the development of an earlier game project conducted in the University of Oulu, titled Janitor Run. More specifically, the goal is to create a virtual reality (VR from now on) game experience from an earlier more traditional game, which was used on a previous study. [1] In addition, the negative effects VR applications induce are identified and studied. Extensive focus is put into the effects of motion sickness, nausea and vection. The two methodologies used to study these phenomena are (1) a brief literature study on the previous research in the field of VR and (2) a two-phased evaluation featuring interviews and questionnaires to determine how participants perceive the effects. Through the data gathered, a more enjoyable, immersive and user-friendly VR user experience [2] is created.

This thesis is done in collaboration with the *Center of Ubiquitous Computing* and is part of the course *Applied Computing Project 1* in the University of Oulu. The previous assets as well as the original version of Janitor Run are all part of a continued game development project, which this thesis aims to continue and improve upon.

1.1. Contributions

Both group members did approximately the same amount of work during the work process for the thesis. Throughout the thesis, work was done for the most part together either by discussing about the subject on hand or by writing at the same time. The background and related work were done by separating the different topics for the group members to work on. Törrönen gathered data for the good practices in VR by playtesting different VR-games and by searching scientific papers and literature concerning those topics. Rapakko on the other hand was in charge of building the brief literature review on the history of VR and the current hardware used globally. The section concerning the common problems in VR was done together by searching relevant studies done on the subject matter.

During the whole project of Janitor Run VR, the development process was done together, and workload was divided equally. The general topics were split up so, that Rapakko focused more on the hardware design while Törrönen did more work towards the movement scheme of the scooter.

The workload during the evaluation phases was divided equally as well. Both of the group members worked as the main evaluator by interviewing the participants and instructing the use of the evaluation gear. While the other group member worked as the evaluator, the other made sure the set-up demo was working as intended and that there were no other problems regarding the software. In the end the workload conducted towards this thesis was roughly equal (Figure 1).

Group Member	Number of Hours
Sami Rapakko	293
Olli Törrönen	280

Table 1. The number of hours that each group member used in this thesis.

2. BACKGROUND AND RELATED WORK

Virtual reality has recently become a topic of interest in the tech-community. It is being marketed and hyped as the next revolutionary thing, and it has a lot of future uses on wide range of different fields. It must be remembered that Virtual reality is not a new phenomenon. In following the chapters, the history and recent development of VR are explored.

2.1. History of VR

In theory the first virtual reality "headset" Charles Wheaton's stereoscope in 1838. [3] It had two images, one for each eye, with small differences that made depth perception possible. The next major virtual reality solution was Sensorama (Figure 1.). It was Morton Heilig's virtual machine in 1960's that used five senses to maximize immersion. The first Head mounted display (HMD) was invented a few years later by Ivan Sutherland and David Evans, also known as The Sword of Damocles. (Figure 2.) HMD was a big stepping stone in a virtual reality's history and it's the basis of all modern VR-solutions. Thomas Furness also known as the father of VR created a flight simulator using HMD in 1979 for military use, providing much needed visual stimulus for pilot trainer. [4] The first commercially available virtual reality solutions came available in 1980's and early 1990's. Since game companies were trying to get players back to gaming after video game crash in 1983 there came to be a plethora of gadgets. First commercially available virtual reality headset was for Nintendo's Famicom, which was only available in Japan due bad sales. [5] In 1995 Nintendo released Virtual Boy to Sega VR (Figure 3.) which was the first console to use 3D stereoscopic graphics. It had red-only screen and poor graphics and thus according to its user's complaints caused headaches and eye strain. In addition, it had to be placed on a table and the user would lean on it in a way that was unergonomic for user's back.

Figure 1 & 2: Sensorama & Sword of Damocles (Figures CC0 1.0 Universal)

After twenty uneventful years the VR got a new coming in the form of Oculus Rift. A Kickstarter campaign was started in August 2012 and it managed to scrape together around 2.4 million USDs, after which Facebook purchased it for 2 billion USD. From that it took four years for the product to appear on stores. [6] At the same time in December 2014 HTC and Valve launched a development build of their VR- product HTC Vive. After and during these time number of different variously priced solutions came from different producers. For instance, Samsung with its gear, HTC with improved HTC Vive Pro, Sony with its PS4 VR-HMD and many cheap products all the way to the cardboard VR-glasses.

2.2. Current VR hardware

Head mounted displays (HMD) are the key element in modern virtual reality systems as stated before and they come in various of different forms. HMDs include the case that covers the eyes and is strapped securely to the users head it would not budge when they move. Inside there is a display whether it be Amoled, LED, LCD or phone screen. Displays show two slightly different images thus creating illusion of third dimension. These images are then fitted and adjusted using lenses to cover the whole specified field of view. Field of view (FOV) meaning the degrees of maximum of 360° either horizontally or vertically that the screen covers. Maximum FOV for human without moving eyes is theoretically 180° but zone where there is 3D vision is only 120° horizon tally and 135° vertically. HTC Vive: 100° horizontal and 110° vertical, Oculus: 80° and 90°. [7]

Figure 3 & 4: Playstation VR & Oculus Rift (© Authors CC0 1.0)

Figure 5 & 6: HTC Vive HMD & HTC Vive Controller (© Authors CC0 1.0)

The controllers can be just mouse and keyboard, console controller or just like in newer models, for instance, HTC Vive and Oculus Rift with their own specially designed controllers. The function is regardless the same, to offer the user a way for them to interact with their virtual surroundings. They can be used in various manners in different applications. For instance, HTC Vive's controllers (Figure 6.) shape and the whole design is based so that they resemble guns. This means that using guns, for example, in games feels more immersive with them than using standard controller. (see chapter 2.4) There are some accessories for HTC Vive controllers that make two handed weapons and other equipment feel more immersive. That controller is still a bit cumbersome and heavy compared to bare hands. Using just hands is the most natural way of interacting for humans.

Figure 7 & 8: Oculus Rift controllers & Magnus Gloves (© Authors CC0 1.0)

So, for example, Oculus's controllers (Figure 7.), they are smaller and fit into hand snuggly and thus allow more precise movement and control. Since humans have five fingers in each hand it is useful to take advantage all of them and thus HTC is developing their own Knuckles, version that in theory would take advantage of all of them. Using Magnus gloves (Figure 8.) and leap motion it is possible transport your finger- and hand movement directly into virtual world.

Movement is natural and important for maximum immersion that is why there is an equipment in few solutions that allow the user to move in a certain area by tracking their movement and translating them into a movement in a virtual environment. There is free movement treadmill, Virtuix omni that allows free movement without user's needing to check if they bump into objects.

Figure 9. & 10: Oculus Rift Beacons & HTC Vive Base Station (© Authors CC0 1.0)

2.3. Common problems on VR

The rise of virtual reality devices has given way to new and more immersive gaming experiences. But they have also introduced a plethora of new problems for game developers, as the increased immersion also requires the user experience to be on par with everything.

The most important issue regarding VR devices is the sickness and nausea users occasionally report having from playing with VR. On previous research it has been concluded, that cybersickness or VR sickness can cause similar symptoms as motion sickness or simulation sickness. These symptoms include headache, stomach awareness, nausea, vomiting, pallor, sweating, fatigue, drowsiness and disorientation. [8] The most common symptoms – headache and nausea – can appear as easily and rapidly as they do in a rollercoaster if proper actions are not taken in the development of a VR game. The root cause for cybersickness is still unclear as many different factors influence users' wellbeing. Movement, for example, is much trickier to implement in VR than it is in the traditional world of gaming, because of the mismatch of the brain thinking it is moving while simultaneously the body feeling like it is not. [9] Acceleration in the virtual world especially induces cybersickness, as "acceleration conveyed visually but not to the vestibular organs constitutes a sensory conflict that can cause discomfort". [10] According to a study made in 1991 another cause for cybersickness could be instabilities in posture. [11] Riccio and Stroffregen argued, that any animal having prolonged instabilities in posture must also suffer from motion sickness, as animals require full control over their own bodies - or perceived ones – to not have their brain be overwhelmed by different sensory stimulations. The same argument also holds against humans playing VR, because if the player does not feel completely in control of their own actions, the symptoms of motion sickness can trigger. Later, the theory was supplemented with the addition, that "women are at greater risk of motion sickness than men". [12]

With VR, another major point of interest and worry is the vision of the user and the monitor of the device. In the traditional gaming consoles and PC's, the game display has been at least a few dozen centimetre away from the player's eyes. But with VR, the screens are right in front of the user, and with that the requirement for better and sharper display grow exponentially. One of the topics that usually comes up with the requirements of VR displays is the screen-door-effect, or SDE for short. SDE is a well-known problem from projection technology and it describes the visible gaps between the actual pixels in the display. [13] An easy solution for the problem would be to increase the resolution of the displays until the gaps are no longer visible, but at the time that is not yet possible. While waiting for the technology to catch up, other countermeasures have been taken to combat the SDE. One of these is the use of diffuser screens, which blur the image displayed to the user so that the effect is not visible. But this too has its drawbacks, as the most common response to blurred images is to constantly try to refocus, which then puts even more strain on the user's eyes.

The illusion of self-motion, i.e. vection, is also one of the more problematic aspects of VR. The term describes the feeling of movement and motion when in actuality the person is completely still. This illusion can be used in a variety of different ways on VR, but the implementation presents a problem. Often when game developers try to produce vection, the symptoms for cybersickness and motion sickness come up. While some studies have proven that there is no outright correlation between motion sickness and vection [14] it is still unclear on how to create continuous vection without the unwanted symptoms. Similarly, with vection, rotational scene movement in virtual environment can induce nausea to user, when experiencing scene oscillation as some studies suggest. [15] In scene oscillation nausea experienced depends on different factors such as duration of the scene rotation.

2.4. VR games and best practices

Technical development of VR has made it possible for different kinds of games to be created as mentioned in chapter one. Games with different genre, for instance, open world, shooting, exploring, puzzle, adventure, driving et cetera have been available for wide variety of people since the release of popular VR headsets like Oculus rift and HTC Vive. [16]

Depending on the game, different solutions can be found to solve problems that VR presents as mentioned in chapter two. For example, movement in VR games is done differently depending on the game, in an open world game Forest VR [17] movement is done by trackpad of the controller. Other practices for movement are teleporting by selecting the point in which the player wants to travel to either by in-game mechanic or by simply pointing the place. For example, in game In Death [18] teleportation is done by in-game mechanic where arrow is shot to the point where the player wants to travel to. More commonly used teleportation is used in VR Dungeon Knight [19], where teleportation is done by simply pointing the location the player wants to travel to. Like this method it is possible to teleport to wanted location in small steps which are visible to the player. This type of movement is used in game Waltz of the Wizard. [20] There are also some other movement styles that are more interactive like swinging your arms like in game Gorn. [21] But there are other traditional ways of movement used in VR games, for example use of keyboard in open-world survival-adventure game Subnautica [22] and steering wheel in simulation racing game Assetto Corsa. [23]

Collision is most often handled in VR games by simply stopping the player avatar when collision happens or by allowing the player to go inside the object and then block the movement of the player avatar. Sometimes player can be allowed to move freely outside the game walls for example in game Waltz of the wizard, but player cannot teleport through the walls, so this limits the area where player can move to. Some games like Payday 2 VR [24] when you enter a game wall you are teleported back to your previous location after some time inside the wall. Depending on the player and style of the game some of these practices might feel better than others. This depends on a lot of factors like style of the game, player and how the collision is done. [12]

One key point in VR games when designing them is how realistic and immersive they feel. By doing so it is possible to reduce motion sickness in VR games. One of these practices in VR games is reduction of the usage of bright colours. [25],[10],[26] Also, the reduction of acceleration in backward, upward and downward motion and the use of visual set point or virtual nose reduces motion sickness and increases immersion. [27] By doing so, sensory mismatch can be avoided between visual stimulus and physical stimulus. In game Pavlov VR [28] there are features like chest rig (Figure 12), smooth movement by trackpad and VR attachments that are allowing different kinds of VR controllers imitating HTC Vive controller. These features in Pavlov VR make the game feel more immersive and realistic. Some solutions can be also noticed in Forest VR, where there are motion sickness reducing features. One of these features is done by limiting the field of view of player when moving to create fixed point. (Figure 13) [8]

There are many game-specific controllers available to VR games. These help the player match the visual and physical stimulus which makes the games feel more immersive and realistic. Some of the game-specific controllers can be found for example in sport games and in many kinds of shooting games in form of a gun. This kind of game-specific controllers are done by using for example VIVE tracker (Figure 11.). There are also controllers as mentioned before in chapter one, like leap motion which tracks the motion of the hand and fingers to the virtual world, [29] this allows more natural way of interacting. There are also some controllers which allow the player to move more freely in games. One of these controllers is Virtuix Omni which tracks the player movement with sensors. The rig of the Virtuix Omni holds the player in one place because the limited area of Virtuix Omni. In addition to these game-specific controllers there are many other attachments and game controllers in the market.

Figure 11. HTC Vive Tracker (© Authors CC0 1.0)

Figure 12 & 13: Chest rig, Pavlov VR & limiting players' field of view in-game, Forest VR (© Authors CC0 1.0)

3. SYSTEM DESCRIPTION

In the following chapters the games functioning, design and various steps that were taken for the final product to take its current form are explained. This includes both the game and hardware aspects. First, taking look at the design aspects and then steps of implementation of the game. Since the basis and premise of the game already existed in a different game, the way it was implemented as a working VR-game is described more precisely in the following chapters. Things that were kept from the original version, necessary changes, improvements and how the results from the evaluations affected the implementation are also thoroughly.

Secondly, the hardware and controller implementation and design will be discussed thoroughly in the chapters below. How the controller was designed and implemented and how it was finally combined with the hardware, meaning in this case scooter and the platform. Since the controller and scooter platform both had many requirements considering user experience with the game. For example, controller needed to be stable in order to allow precise tracking and platform had to be stable and hard due to the tracking of Wii Balance Board [30], so the player of the game would avoid unnecessary loss of stability. All these aspects were taken in the consideration when designing and implementation was done.

3.1. Game Design

Before it was possible to start developing Janitor Run VR, it had to be planned how the project would be done software wise. There were two competing development platforms to choose from “Unreal Engine” and “Unity”. The latter choice felt better suited for the project because of Unity’s user-friendly game development, support found through the internet, better asset store with wider selection of assets and the fact that previous version of Janitor Run was developed in Unity. Although Unreal engine had better graphics there were no university assets that were readily available. In case the choice would have been Unreal Engine, there would have had been used more time in the development process and the time frame would not allow that, so the chosen platform was Unity 3D.

Game design aspects and almost all game assets were clear and available to use in the beginning of the project (Figure 14). Some exceptions were assets that considered VR aspect of the game and some implementations that were planned to be added to the game. One of those aspects was main menu, user interface (UI) (figure 15), kicking scooter and use of Wii Balance Board in the game (figure 17). This added a new layer to the movement of the game. How it should be taken in consideration in the development of the game and would we need some software to handle the data that Wii Balance Board presents. First answer to this problem was thought to be Wii balance asset from Unity store but it turned out to be unavailable for the development, so instead Wii balance walker [31] is used (figure 16). It connects to the Wii Balance board and takes data and makes it possible to setup certain threshold values that trigger certain user set events. These thresholds are triggered by the user, by leaning weight to a certain point of the Wii Balance board. In the Janitor run’s case W and S for forward and backward respectively.

Game logic would follow the same logic that was in the previous version of Janitor Run but it would be necessary to change some things considering gameplay, because the game would be developed in VR. It would be preferable to keep the gameplay smooth and set importance to movement of the player in game as it would play big part how immersive the game would feel and how it would effect in motion sickness which is common in the racing games in VR, due to the acceleration. [10] Some changes that would be necessary to do were to remove or change some features which the previous version had. More detailed description of the elements that were changed and removed see chapter 3.3. It was also a plan to add multiplayer in the game, but this idea was later dismissed as it would not play big part in the game and since the time constraint limited development time.

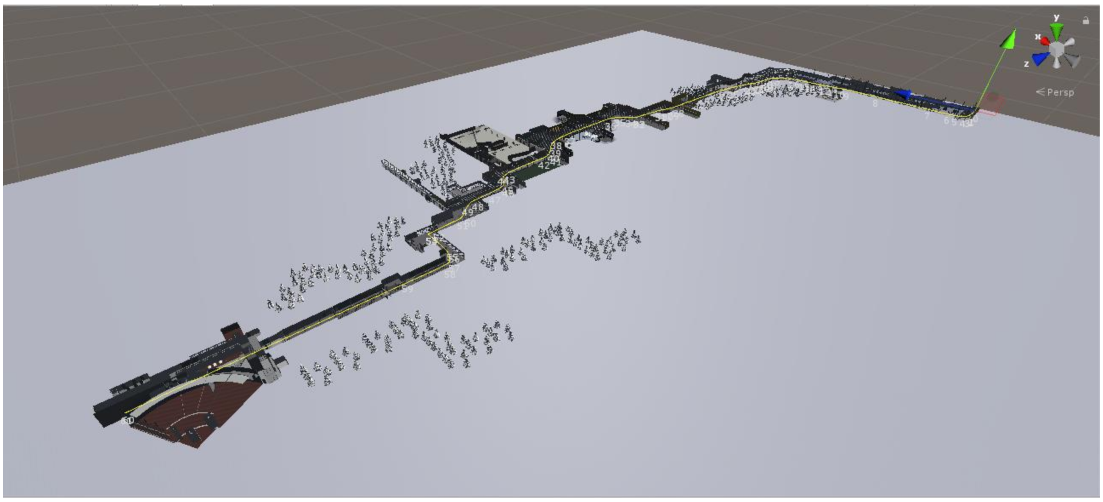

Figure 14: University scene and the assets it holds. (© Authors CC0 1.0)

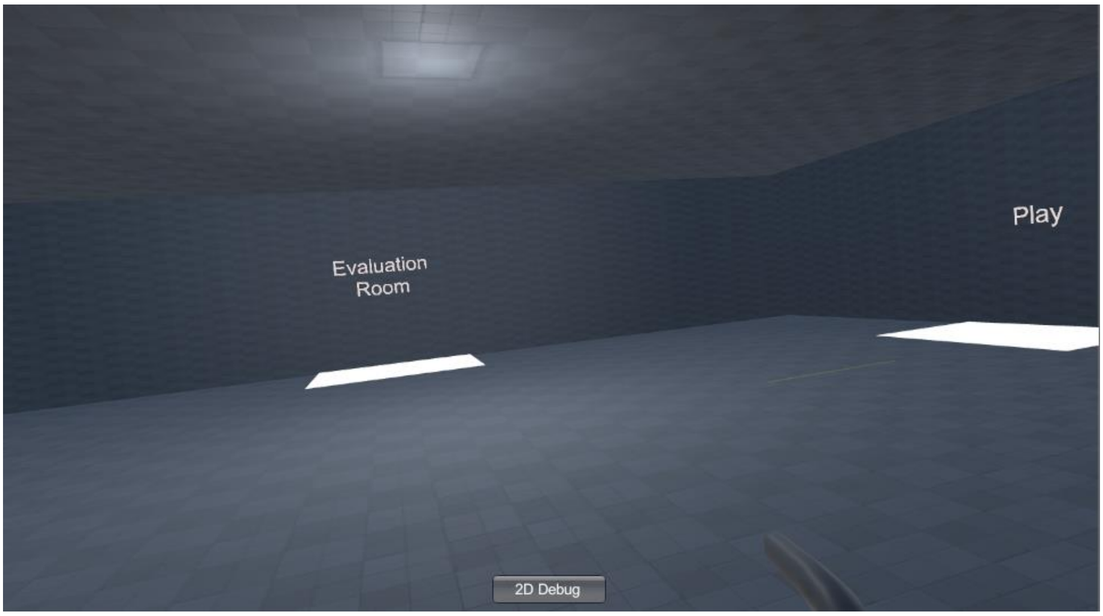

Figure 15: Early stage of main menu. (© Authors CC0 1.0)

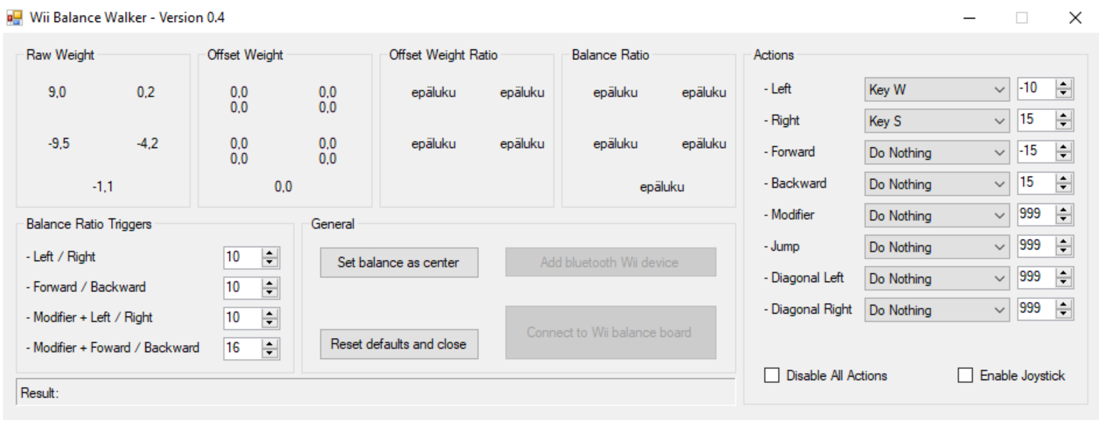

Figure 16: Wii Balance Walker interface (© Authors CC0 1.0)

Figure 17. Wii Balance board (© Authors CC0 1.0)

3.2. Controller Design

The development of Janitor Run included a unique controller to be used alongside the base game to add another layer of immersion for the player. As the game is focused around moving in a virtual environment with a kick scooter, the first thought was to make a controller from an actual modified kick scooter. Within this custom *scooter controller* HTC Vive's controllers would be attached to its handlebars to make the movement as seamless as possible. After a lengthy search period, it was decided that the holders for the controller was to be 3D printed, as that would allow complete freedom in designing the control scheme in the game as well.

The design of the first prototype revolved around placing one HTC Vive controller next to the core of the handlebar. And, as unity could read the subtle movements of the scooter just as well with just one controller, there was no need for the second controller in the design. This would also eliminate the fact that controllers may change their handedness and possibly mess up controlling with specifically handed controller which was noticeable in early testing sessions. The controller holder placed the controller directly parallel to the main handlebar (Figure 18). Later on, when it was revealed that the first design was flawed, another prototype was designed. This time the controller was no longer parallel to the handlebar, but instead placed the top of the controller horizontally levelled with handles so that the controller would be able to measure a wider scale of movement correctly (Figure 19). With this design change, the controller was also able to measure movement in the Y-axis.

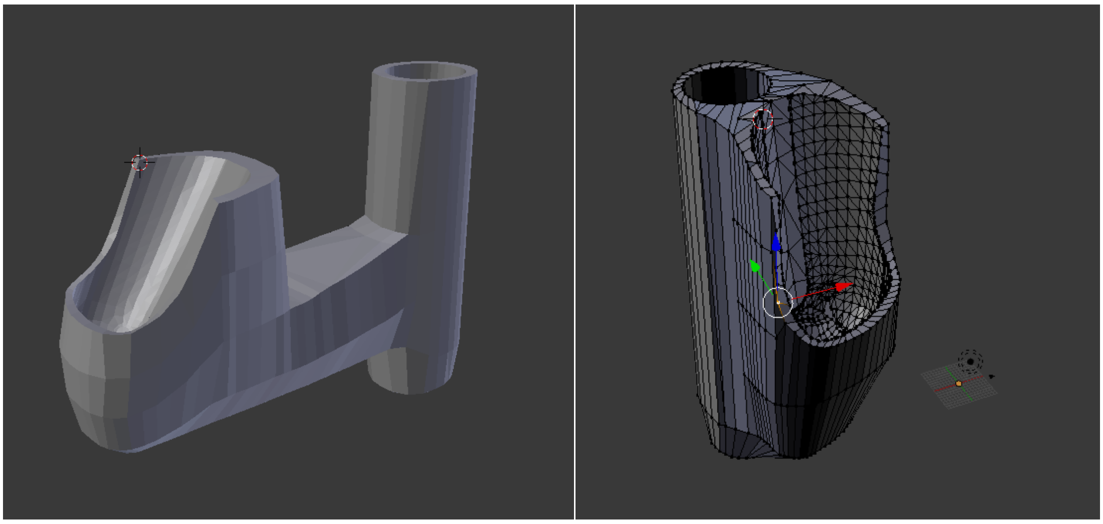

Figure 18 & 19: 3D models of the controller holders. Left is final design. (© Authors CC0 1.0)

Another point of interest for the controller was to design a way to measure if the user was kicking forward or not. Multiple different methods were thought for this, but ultimately it was chosen that the kicking would be measured with a commercial version of Nintendo's Wii Balance Board. The balance board offered a cost- and time-effective way of measuring accurate feet movement and would be easy to combine with the rest of the scooter controller.

The board and scooter had to be placed so that it would be easy to use and versatile enough to move. There were a few designs that boasted these features, one of them (figure 20). The chosen prototype design features a metal frame for scooter to be fixed to and a place on either side for balance board to be placed so that the player would be able to choose which side they are more comfortable to kick from. The balance board is supposed to stay in place with boards non-slip rubber pads that would prevent the board from slipping when the player is using the board. The kick scooter on the other hand is placed on top of a railing that complemented the original shape of the kick scooter deck and then is fastened with screws so that the whole system would be steadily in place even when the player is immersed heavily in the game.

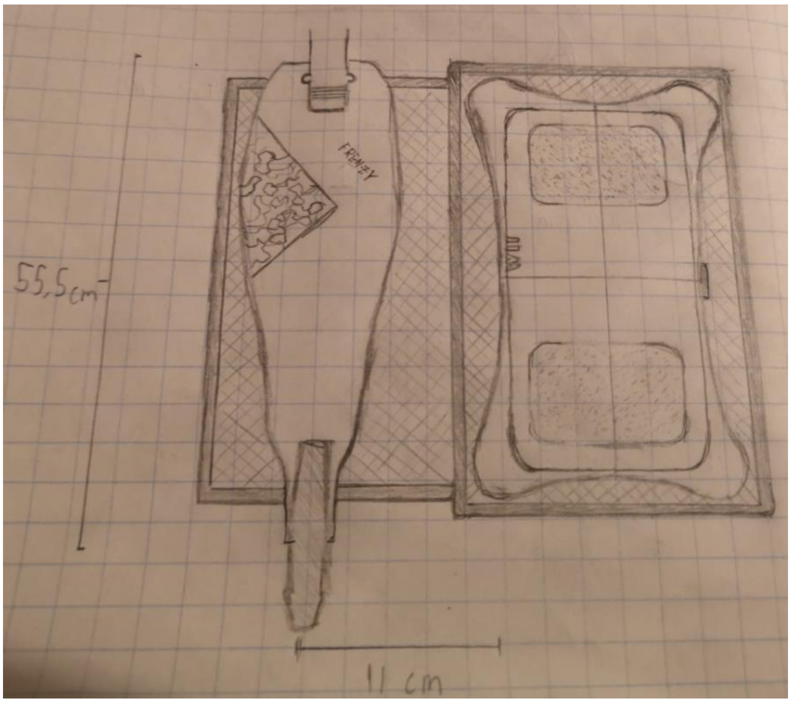

Figure 20: Concept design of the balance board frame. (© Authors CC0 1.0)

3.3. Software Implementation

In following chapter, the implementation of the game and its development is discussed. It is done in two phases. First phase looks through when implementation before playtests and second phase when some aspects were changed because of comments that were received from evaluation. In addition, challenges that were faced during production. Clearly biggest problem and concern was movement since it took the longest to implement and the most attempts to get right.

3.3.1. First prototype

Since the previous version of the game was made to be third person game changes had to be done in order the game to be playable in VR. Things that were mentioned in the previous chapters about motion sickness to the immersion and investment of the player to the game not to mention playability. Directly exporting the scenes and testing them in VR it was visible through very low frame rates that major changes had to be done. Thus, Steam VR's default lighting was used instead and that was then tweaked to suit the game's needs i.e. Lighting was adjusted to be darker in since too bright lights and contrasts [10] may induce symptoms in players. Since there were a lot of lights inside the university, those lights were baked; pre-calculated illumination that is added to the light maps of the static objects before run-time, into the scene and the subtle global lighting would provide ambient light. The original model let the global lighting inside the buildings so they were removed since in the real world that would not happen either and that also helped in making the place darker. The weather effects were removed since they looked very distracting and would only drop frame rate and cause nausea in the game, especially since it was raining inside.

In VR it is not advisable to use any UI elements that are stuck to the view of the player. [10] Based on this information the time keeping and all other game elements such as map selection are done using the in-game elements, such as teleports and screens. These large screens play a part in helping the player navigate through the university. [32] Time tracking will be shown on the screens positioned near the checkpoints and would be triggered when the player hits the corresponding checkpoint. From original the path the player could follow so they would know which way to go was let to be since it was a in-game element and would not harm experience even though it is an element that would not exist in real world.

Regarding the movement, it was decided that the game would not use the original movement scripts that were introduced in the game assets. Best solution seemed to be to use car assets that were available in the assets store and change these scripts to our own use. Major changes that were made to these scripts were mainly done to the control of the scooter, since the player would control the scooter in the game with the scooter's handlebar. It was made so that the HTC-Vive' controllers z-angle is tracked to allow the handlebar to resemble the real-life angle of the angle of the scooter's handlebar. Since the script was made to be used in car objects, it needed some major changes to resemble more scooters movement. The movement script was edited so that the movement mimicked the kicking motion that is induced in real-life. While this progress was ongoing big changes were made to movement script and values of the attributes were edited to make the movement more responding and realistic. These attributes being mass, velocity, angular velocity, max speed, traction, forward- and backward torque. The values were chosen by the developers of this study when testing the game. For testing and tweaking these agreed upon values the evaluation room was built as its own map for the project. It would appear in both phases and would provide the environment where user could freely test movement of the scooter. For evaluation room, it was necessary to provide player various situations where they could experience the movement of the scooter so that they could assess the performance of our current movement values. That's why there were gentle ascending and descending slopes, roundabouts, 90-degree orders to either side. In addition, there was added place where the user would cross a hole through narrow passageway to assess how precisely the user can control the scooter. After that there was a more open place where the player could freely test the scooter's movement.

Regarding sounds, since the focus of the first prototype was movement the sounds were thought as neglectable. They would not add to the movement assessment and would in worst case distract from and affect the judgement of the movement.

3.3.2. Second prototype

After the first playtest, the movement script had to be edited a lot due to the results of the tests. Also, the scooter was deemed to be an electric scooter and to move the scooter by kicking was removed since the test revealed that with current system it would not be possible. Also, backward motion was changed slower and braking was made more effective. Because of the removal of the kicking motion it was noticeable that the movement felt more responsive and natural with the Wii-board. While this progress was ongoing big changes were made to movement script and values of the attributes in the movement script were edited heavily to make the movement feel more responding and realistic. Overall the movement was edited to be more slow-paced and controlled.

As there were comments about improving immersion by adding sounds to the experience after the first phase, some were added. Sounds improve players immersion so it should also reduce symptoms the game may induce. [10], [33] The most important sounds that came up regarding the first prototype were the sound of moving scooter and sound when you bump into the walls. Background music was also added to improve immersion, [34] since the game has consumable object it was good to add sounds when the player consumes them. These sounds do not have to be spatialized since they come basically from the players close proximity and would not cause any immersion breakage.

As mentioned previously there were consumable objects; hamburgers and coffee that were kept in the game. Their effect was changed thought, since increasing the speed of the user by boosting would make some players sick, which was apparent from the first play test. Too fast scooter contributed to the increased feeling of sickness and loss of immersion. There had to be some point for the consumables so in the main menu there is a counter and when the user collects five consumables it would open a secret ramp room behind the counter.

It was noticed though observation of the test subject that they had difficulties navigating their feet on the board of the scooter. This was since the game used the original model from the previous version of the game. Since, the board that was used as the controller had smaller sized deck it created mismatch between controller and the virtual board. Hence, the model that resembled the real board was made using Blender to closely resemble its real-world counterpart. The test subjects still had some difficulties with their feet but not nearly as much.

3.4. Hardware Implementation

The implementation of the scooter controller began with 3d printing the first controller-holder's prototype. To do this, a 3D model of the prototype was created using the open-source software Blender, which then was converted into a 3D printable shape with the help of another open-source modeling software FreeCAD. Then, with the help of a few wonderful people from the university's fabrication laboratory (FabLab for short) a first prototype was printed. This prototype featured a holder for one HTC controller and was positioned in an upwards position (figure 21). While the prototype was successful in the way, that it kept the controller steady and was sturdy enough to not move even in the most violent outburst with the scooter handlebar, it had one design flaw: it placed the controller in an awkward position to be tracking the handlebar movement. In addition, it proved to be harder than anticipated to model the scooter in-game with a slightly tilted HTC controller, so it was decided that a new model was to be created. The new model went through the same design phase as the previous one with one slight difference. This time it placed the controller in a position, where the controller's tracker was directly above the handlebar and horizontally straight (figure 22). This change in design helped with the scooters modeling in-game and proved to work so well, that no further changes were necessary.


Figure 21 and 22, the two prototypes for the controller handle. (© Authors CC0 1.0)

The second part of implementing the hardware design was to create the frame for the scooter and balance board. Before in the design meetings it was decided, that the university's engineering workshop was to be used with implementing the scooter frame, as none in the Janitor Run VR development team was familiar with mechanical engineering. This unfamiliarity proved to be a downfall at the workshop, since the machinery there required at least some sort of experience in order to be even able to use them. Fortunately, the people working in the workshop agreed to create the metallic scooter frame according to the design documents on the basis, that the project was at least partly for the benefit of the faculty of technology. The end-prototype of the scooter frame (figure 23) featured a large metallic platform to stand on and to place the Wii balance board comfortably on either side of the scooter in according to the preferences of the user. The scooter itself was fastened with multiple screws to the metallic platform, so that no matter how violently the users would wrangle with the scooter controller, the scooter would still sit in place comfortably. There were no modifications done to the scooter above the base, as the handlebar required full control over movement and the design was also to be kept as close to an authentic kick scooter as possible. Finally, a small carrying hole was cut to the metallic platform to allow easy transportation of the scooter-controller.


Figure 23 and 24, the scooter controllers metallic frame with the balance board. (© Authors CC0 1.0)

With both the controller holder and the steel frame for the scooter finished, the hardware implementation had reached its end. The finished scooter-controller allowed unhinged movement of the handlebar, precise and sturdy tracking of the HTC controller as well as easy placement of the balance board. It was also a stable platform to stand and kick scoot in. The created unique scooter-controller (figure 24) was a welcomed addition to the gameplay experience of Janitor Run VR.

4. EVALUATION

The evaluation plan tells why and how the evaluation was planned to be executed. It shows the scope of the study and explains what kind of people and how many are planned to be participants of this study. Additionally, we – the development team – wanted to evaluate the movement and *feel* of Janitor Run VR. In the next chapters it will be explained why there were two phases in the evaluation and what their ultimate purpose was. This is done due to the idea that, if the phases are done correctly it is possible to attain some quantitative as well as qualitative data that can be then compared. The compared data can then be analysed to reach conclusions and to maybe find correlations between opinions of the participants between the two phases.

4.1. Evaluation purpose and scope

The purpose of this evaluation was twofold; the first evaluation phase measured how well the control scheme, movement and the scooter controller work from the eyes of a new user. Aspects such as motion sickness, ease of use and immersion were also be kept in mind when acquiring valuable evaluation data, as these topics were immensely important to the end development cycle of the project. The second evaluation phase focused more on the enjoyability and playability of the game and it would be conducted at a much later date, when the game was nearly finished, and it only needed some fine-tuning. With these two evaluation-phases the most important aspects of the game would be evaluated.

4.2. Participants

For the evaluation to be a success, it was recommendable to recruit a reasonable number of participants. Optimally, the amount was aimed to be around 10 to 16 people with varying amounts of experience with VR. On top of that the gender ratio was tried to keep relatively close to 50/50, as to see if there were any measurable differences in VR movement between genders. For the first evaluation phase the recruited participants were from the social circle among us the developers. On top of that it was desirable to recruit some strangers from around the university's campus to mitigate the "friend bias" that might have otherwise occurred.

4.3. Evaluation protocol

The protocols in which the evaluation phases were done is explained in the next chapters. How the evaluations were hold, in what environment, how the questionnaires were done and what was the aim of the questionnaires. Both phases were done similarly in hope to achieve comparable quantitative and qualitative data between phase one and phase two. This is done so that the evaluation phases were done with a similar questionnaires and evaluation test. The changes were done mainly into the game itself, excluding some minor changes that were done to the questionnaires. This is allowing us – the developers – to use the data in a way that the changes that were done after phase one will affect the results of the questionnaires. The changes between these two phases were small, so it is possible to see correlations between the minor changes done in game and questionnaires. The details in which these two phases will differ, will be explained more thoroughly in these chapters.

4.3.1. Evaluation phase one

After recruiting the needed participants, they were all asked to fill in a consent form (appendix 1) that released the evaluation authors from possible consequences, for example a participant falling during the evaluation, or feel some nausea. Other point of the consent was to be sure that the next participants that would participate in this study would not hear about this study from earlier participants. In this way it would be possible to avoid participants, that would have had some expectations towards the evaluation. After this, short interview was hold in order to attain users age, gender and experience with VR. Before the evaluation test a small briefing took place, and after that the users were instructed to start the game's test level. This level was just a short and simple test course, which emphasizes the movement of the game above all else. There were slopes, tight turns, narrow paths and open areas to explore in order to allow the participant to experience movement more toughly. The user did not have to operate any opening menus or system settings, as all the technical preparation was done by the evaluation authors. When the user was experiencing the test course, the play through was followed closely and the evaluation test was possible to end early, in the case that participant experienced so.

Immediately after completing or trying out the test course, the participant was instructed to stay in the evaluation room and fill in a custom-made questionnaire (appendix 2) evaluation the VR experience that they had just experienced. The decision to use a custom-made questionnaire instead of a standardized one – for example the well-known Simulator Sickness Questionnaire (SSQ) by Kennedy et al. [35] – came from the fact that only a few standardized questionnaires focused on the actual movement scheme within a virtual reality experience. And the few questionnaires that did were worded so obscurely that they might affect results given by the participants, who for the most part were completely Finnish. After explaining the questionnaire answering process, the participant was then left alone in the room to ease the feeling of being under pressure by the evaluation author and the participant was given a maximum of 20 minutes to complete the survey. In case there were some problems understanding parts of the questionnaire, participants were guided to ask explanation about the subject. This second questionnaire implemented the Likert scale in order to evaluate the ease of motion, immersion and control scheme of the game. Each major topic of interest had two to three questions dedicated to them asking whether the functionality worked, and if it was smooth/easy to use on a scale of 1 to 5. Each topic was also featured in an open-ended item, where the participant was free to give any feedback, they had concerning that feature. With this questionnaire there was a hope that this questionnaire would gather some quantitative and qualitative data concerning the motion in Janitor Run. This data would then play a big part in a development of the game before the second phase considering major elements of the game.

4.3.2. Evaluation phase two

When the development of Janitor Run reached a point, where the developers were satisfied with the movement and other game aspects – such as the university model, sounds, et cetera – the second evaluation phase began. These changes were done due to the results of the first phase, more detail about these results can be found in chapter 5.2. In this phase completely new participants were needed to be recruited, as fresh eyes were very important to the evaluation. Since one study suggested that habitation to VR environment can decrease symptoms of motion sickness induced when playing VR games on multiple occasions. [36] The evaluation method stayed same as in phase one with the difference being that the topics and questions in the questionnaires and interviews were more focused into the enjoyability, playability and motion sickness, also the participants went through the university level. In addition to the consent form that was filled similarly with the phase one consent form, oral consent was asked that allowed evaluation authors to record open item questions that were hold in the beginning of the evaluation and in the end of the evaluation. With the same evaluation practices, it was possible to acquire more qualitative and quantitative data concerning the end development of Janitor Run. As a whole, the phase two evaluation was planned to work as a fine-tuning tool to address the final problematic topics of the game and to achieve some correlative data.

4.4. Analysis

The data gathered through the evaluation was analysed in two steps; in phase one and two respectively. The analysis of the first phase focused on difficulties towards the movement scheme and how to improve it, and since there was a rather low number of participants (n = 12), the data analysis was done mostly by hand. The quantitative data from the questionnaire was all collected into one excel "master" sheet, from which graphs from each individual question were made. All the qualitative data from the open questions and interviews on the other hand was written into one-word master document, where all of the answers and recommendations were easily found. Each answer was also done anonymously. When both the quantitative and qualitative findings were gathered into one-word document, the whole development team went through each question, answer and recommendation in order to better Janitor Run VR as well as the evaluation protocol for the second evaluation phase. The data from the second evaluation phase was analysed similarly with one slight difference. This time, while every participant (n = 12) was totally anonymous, each had a corresponding number to keep track of what background info was related to each answer. This way the development team was able to see if there were any correlations with the second phases background question answers and the questionnaire answers. Finally, when all of the second phases answers were analysed and transported to a single master document, the development team went through the findings comparing the results of the two different phases.

5. RESULTS

Evaluations phases went according to the evaluation plan and there were no major differences between the execution of phase one and phase two of the evaluation. Only some small changes were done to the questionnaire and to the test. These changes were done due to the reason that there were some misunderstandings with some of the questions with the participants, or there was a need for different data. The need for different data was due the added playthrough of the university map. This allowed us to test the university game area more thoroughly. After the first phase there were some clear areas that needed changes or further implementations, for example sounds were implemented and movement in-game was edited to be more slow-paced and controlled, as a result from phase one evaluation. Due to these changes there were clear difference between evaluation phase one and phase two results and this showed how the game changes affected the results of the whole questionnaire.

5.1. Quantitative Findings

In the quantitative findings (appendix 4) there were a lot of correlation between the two phases, but a few answers stood out. The first of these is the very first question on the questionnaire (figure 25), where the participants were asked to rate on a scale from 1 to 5 to how much they agreed with the following statement: “I was able to control the events well”. While the majority of the participants on both phases agreed, that they were in fact able to control the events well, a significant portion on the first phase neither agreed nor disagreed with the statement. But then on the second phase, only one participant disagreed with the statement, when all the other participants either agreeing or strongly agreeing.

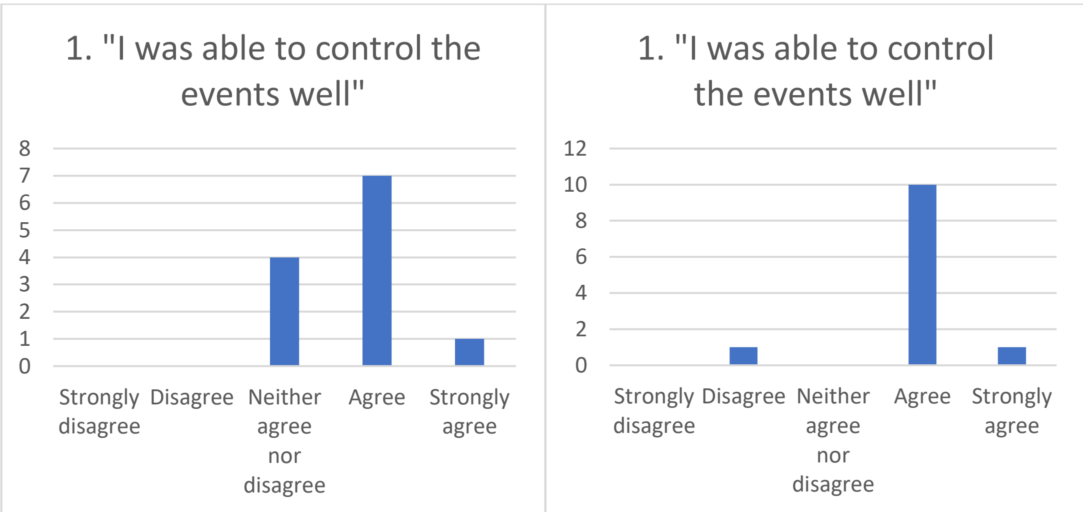

Figure 25: Questionnaire answers for the first item for phase 1 (on the right) and phase 2 (on the left). (© Authors CC0 1.0)

The second interesting find came from the sixth item on the questionnaire (figure 26) which had the following statement: “I felt discomfort or nausea during the virtual experience". On the first phase the answers were spaced out somewhat equally across the board, with the slight majority reporting that they agreed with the statement. On the second phase though, the majority reported that they disagreed with the statement, implying that the nauseous nature of the game was reduced between the evaluation phases thanks to the corrective measures taken after the first phase.

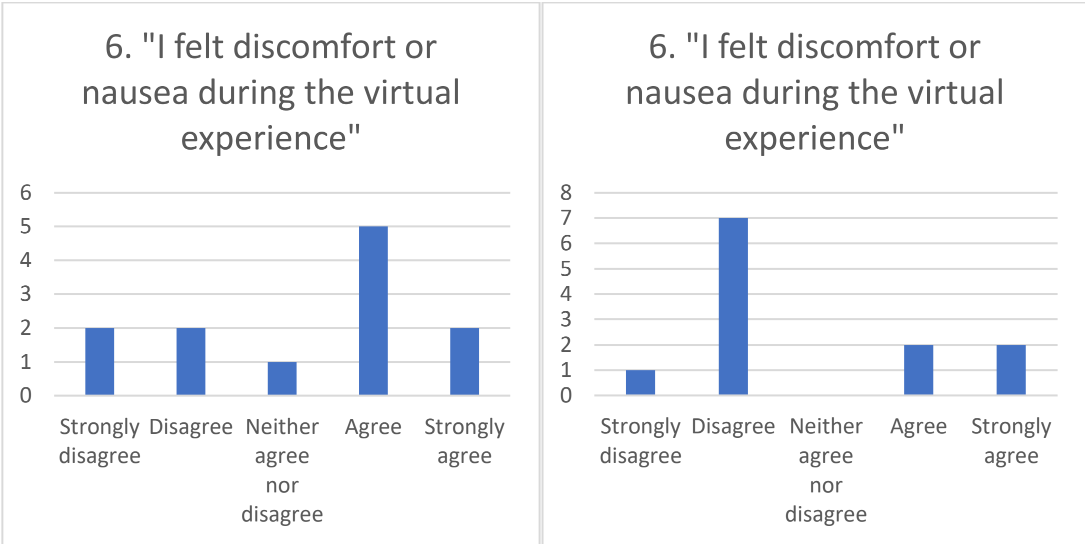

Figure 26: Questionnaire results for the sixth question for phase 1 (on the left) and phase 2 (on the right). (© Authors CC0 1.0)

The third major quantitative finding was the fact, that the results implied the movement scheme was improved between the evaluation phases. In the eight question (figure 27) on the questionnaire - "I was able to move well in the virtual environment" - the majority shifted their opinion from agreeing to strongly agreeing between the two phases. With the second phase there seemed to be one outlier in the group, which reported strongly disagreeing with the statement concerning the successfulness of the movement.

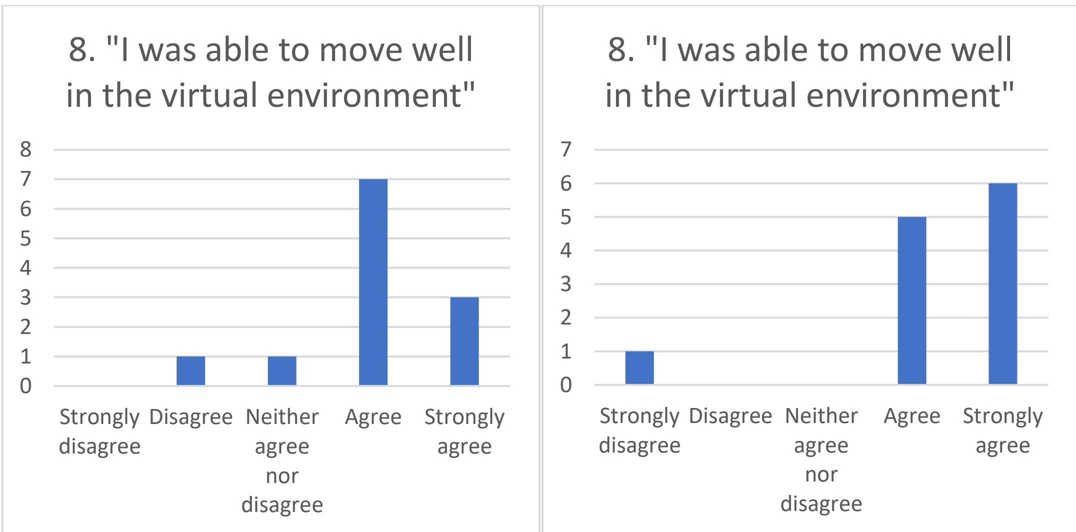

Figure 27: Questionnaire results for the eight question for phase 1 (on the left) and phase 2 (on the right). (© Authors CC0 1.0)

The final interesting quantitative findings came solely from the second phase' answers, as a select few questions were modified between the two phases to serve the needs of the development team better. One of these questions was the fifth item, "The virtually recreated university was modelled well", where half of the participants agreed, and half strongly agreed with the statement (figure 28).

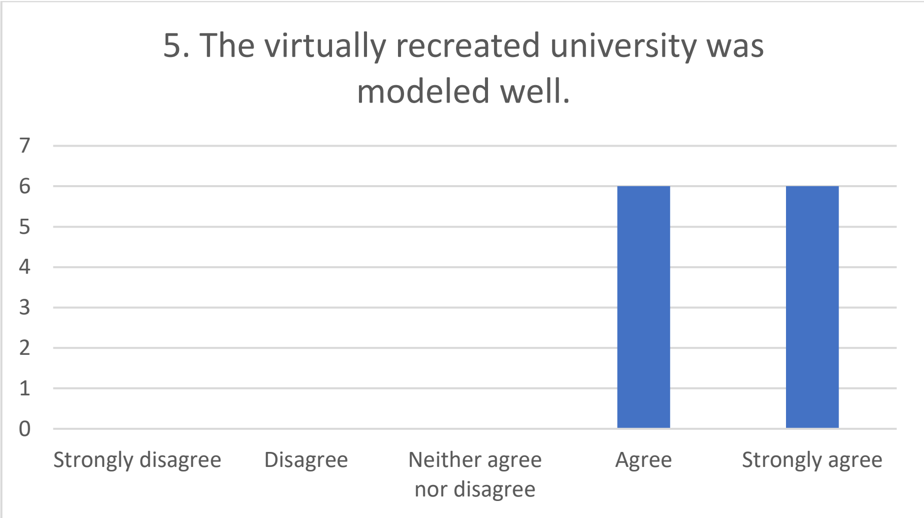

Figure 28: Questionnaire results for the fifth item for phase 2. (© Authors CC0 1.0)

5.2. Qualitative Findings

Whereas the quantitative data from the questionnaire was easily compared between the two evaluation phases, the qualitative data gathered had to be analysed separately for both phases. This is due to the facts, that the questions changed slightly, the environments were different for the phases and the wordings used when describing the system and the control scheme were different for the second evaluation phase.

5.2.1. Qualitative Findings for Phase 1

The first open-ended question brought some invaluable insight on how well the movement scheme responded to people who were new to the Janitor Run VR experience. The question went as follows: "[d]id you have any problems with the movement? If you did, explain in your own words what these problems were". According to the majority of the participants, the acceleration and deceleration seemed unnaturally fast and one participant even reported that they "lost balance a couple of times because [they] thought [they] would fall" (appendix 4). A very slight minority reported that they felt the movement to be natural and easy to use.

Another notable qualitative finding came from the answers concerning the question about whether or not the participant felt discomfort or nausea during the session and what they thought contributed to those feelings. Of the twelve participants in the phase 1 evaluation, nine reported some form of nausea, discomfort or dizziness. While the majority of the participants were unable to describe what exactly contributed to these unwanted feelings, some expressed how the turning was at fault for not feeling natural enough. Some also noted how the unnaturally fast acceleration and speed felt like the most likely culprits for discomfort and nausea: “the sudden change in the speed caused a little bit of nausea. The same kind of situation where I would normally feel motion sickness”.

5.2.2. Qualitative Findings for Phase 2

The qualitative findings from phase 2 were quite unexpected, as the feedback for feeling nausea or discomfort was much more positive than in phase 1. This time the majority of the participants reported that they felt no kind of nausea or discomfort during the VR experience. Some even revealed, that while they usually do feel motion sickness when traveling, they did not feel any kind of discomfort or nausea with the experiment. Still, a noticeably minority reported some kind of nausea or discomfort due to a plethora of reasons (one being that the game did not register the change in balance for the user). Especially one outlier in the group answered, that the evaluation experience was the most nauseating VR-experience that he/she had ever tried. (appendix 5)

Another interesting find in the qualitative data from the second evaluation phase was, that every single participant seemed to report enjoying the experience. One participant especially seemed to enjoy the VR experience, as “it was cool to see the university in VR form and fun to cruise around it”. A few participants mentioned how much they liked the scooter controller and how it was a unique VR experience unlike any other.

The final - and arguably the most important - qualitative finding came from the last open -ended questions’ answers. The question itself was from a previous study conducted by Usoh et al., [37] where they depicted the first SUS (Slater-Usoh-Steed) questionnaire, which evaluated the immersion and sense of being in a virtual environment. The modified question that was used for the phase two evaluation went as follows: “[w]hen you think back to the experience, do you think of the virtual environment more as *images that you saw* or more as *somewhere that you visited*”. Out of the twelve participants nine described how the experience felt more like a place that they visited rather than images that they saw. Two participants reported that they felt the experience more as images that they saw, and one participant reported that they did not understand the question and thus left the answer as unknown.

6. DISCUSSION

6.1. Implications

The results of the evaluation seem to indicate, that the numerous design choices that were made in-between the two evaluation phases, improved the feeling of being in control and being able to move well in a virtual setting. The first and biggest change in the movement design was to decrease the acceleration of the kick-scooter, as the majority of the evaluation participants commented it being unnaturally fast in the first phase. Remarkably, after the change, the evaluation results concerning the movement turned more positive, as the maximum speed and acceleration were adjusted to be much closer to a realistic kick scooting experience. The changes to braking and reversing also seemed to help with feeling of being in control, and it can also be argued that playing in a more open environment - one containing more spacious hallways to kick scoot in - also helped with that regard.

Playing in a familiar setting - i.e. in the university of Oulu - also seemed to have an effect to the level of immersion the participants reported. The qualitative findings concerning the question of rating the experience more as images or as a place visited seemed to indicate that the experience was immersive. The participants rated the immersion highly in the first evaluation phase as well, but with the second phase the virtually recreated university felt more familiar and a better environment to play in. And, as all of the participants were part of the Finnish academia, the virtual university was a very familiar setting. The inclusion of real-world elements - in this case, the university - in the evaluation could have also had an effect on the perceived comfort during the experience, which would reinforce the theory brought forward by Rebenitsch & Owen. [38]

The most important implication that the results brought forth, though, was how big of an impact minor changes seemed to have to the perceived motion sickness and discomfort. In the first evaluation phase the majority of participants reported feeling at least minor nausea or motion sickness, but then on the second phase, the results showed just the opposite. As with the ease of motion, the biggest contributor to this change seemed to be the decreased movement speed and acceleration. The more realistic the movement speed and acceleration were, the less the participants reported feeling nausea or discomfort. Surprisingly, this goes directly against the best practises of VR according to the Oculus Developers [10], in-which they state that, “unnaturally rapid velocity has also been shown to be less discomforting than a normal human pace”. Of course, since in Janitor Run VR the locomotion technique is a scooter, the typical best practises of VR might not apply as strongly as in other VR applications. In addition, the use of music as well as audio cues in-game for the rolling of the scooter’s wheels and moments of collision seemed to have a positive impact on the perceived discomfort as well. These findings are in line Keshavarz & Hecht [34], who demonstrated how pleasant music can be a valid countermeasure against motion sickness.

Other causes for the lessened feeling of motion sickness and nausea were perceived to be the more realistic kick scooter, and the change in the instructions when telling the participants that the control mechanism was more akin to an electric scooter rather than a kick scooter. The in-game model of the scooter was changed after the first evaluation, as the previous version was perceived to be smaller and not accurate enough for the real-life counterpart. The new scooter model - with its wider deck and more accurate measurements - lead to fewer trippings when stepping on the custom scooter controller. The change in the participant instructions when discussing the optimal movement strategy in-game similarly led to fewer balance issues, as the participants no longer tried to move by kicking, but rather by a kind of pedal movement scheme similar to that of an electric scooter. And finally, even when motion sickness and nausea did occur in the participants, the enjoyability still seemed to be quite high (figure 29), reinforcing the idea introduced by Von Mammen et al. [39], that “[c]yber sickness does not necessarily take away the fun in games - it may be a part of it”.

6.2. Limitations

While this study can offer some implications towards how to mitigate motion sickness and nausea, the study did have some limitations. The first of which being, that the questionnaires used were all only in English, even though the majority of the participants were Finnish-born university students. While the quality of understanding English literature is quite high in Finland, it could be argued that the results might change slightly, if the questions given to the participants were written in their mother tongue. And even though the participants were instructed to ask for help from the evaluators in the case that they did not understand the question(s) fully, the participants could unknowingly interpret the questions or given answer options wrong.

Figure 29. Participant enjoying the VR game experience (© Authors CC0 1.0)

The biggest limitation of the study would still have to be the fact, that the sample size in both of the evaluations was quite small (n1 = 12 and n2 = 12). The study would have benefitted from a larger sample size, as with a sample size of twelve participants, outliers and trends cannot be identified as accurately. The range of participants could have been more diverse as well, as all of the participants were Finnish academia. In addition, the age as well as gender distribution were more focused on mid 20's and men respectively, creating a monotonous group of participants. The age distribution especially would have been interesting to see more diverse, since according to a pilot study by Arns & Cerney [40] older participants suffered more from motion sickness in virtual environments than younger ones. And, while the one older outlier in participants did report stronger discomfort and nausea than others, no significant conclusions can be made due to the limitations of the study.

6.3. Future Work

As it has been previously stated, there is a plethora of things that can be further developed and improved in the software as well as hardware. The next chapters describe possible changes and future improvements that could made to the existing version better and a more enjoyable VR- experience, as well as potential future studies.

6.3.1. Future Software

As mentioned in the implementation chapter, the controlling and the way the scooter is handled is subject to many changes. In the evaluation's second phase there was still a minority of people who felt that the experience was not realistic, especially the movement, which according to the research data was improved. The disconnect between reality and the game was also increased by the environment, the controller and some technical implementations.

Controller- and movement-related matters can be improved in future iterations by adjusting the values mentioned in the implementation chapter, for instance torque and angular velocity. By adjusting these values, the movement could be made to closely resemble the movement of a real kick scooter and hence improve the immersion of the players. In addition, the virtual replica of the scooter controller could still be improved, since some of its measurements – especially its width and its deck – are too narrow compared to the real scooter. The size difference was noticeable, as when some participants tried to place their feet on the deck, the mismatch between the virtual and real scooter caused some issues in stability and foot placement. So, making the measurements more accurate in all axes would improve players' comfort using the controller and provide better playability. Players' hands are not visible in the game so tracking them or showing them when they hold the handlebar would help players to keep track and be aware of their hands better when playing. One solution could be to make human avatars for players and add hand movement tracking, for example, with the Magnus gloves increasing immersion in the process.

The environment is also one of the factors that causes disconnect from reality. In ways like graphics and the way things are represented affect the players feel of their surroundings. The university environment that was developed for the previous version was designed for a 3rd person game and did not match reality since most of them were flat and lacked texture and correct mapping. As mentioned before, parallax mapping should be used instead of normal mapping, since the normal mapping does not work with two eyes when used in virtual reality applications. Also, having less details in objects is not realistic and thus contribute to the lack of immersion towards the game. Lighting was also an issue in the scene. One of the iterations was thought to be implement but was dropped due to the drop in the graphical performance of the game in the form of frames per second. A better lighting could be implemented in the future by making improvements to the underlying setups, for example by making it more efficient. This also encompasses the shaders and reflectors.

When it comes to the menu scene it is bare bones. In further iterations the menu could be made more approachable and there could be instructions to the players which make it possible for the users to play the game independently. In the game scene the player is dropped right into the action, so for the players' comfort there could be a delay when moving into position so that the players have time to adjust. Otherwise the player might not be ready and, as the game is all about racing, a loss of time due to sudden transitions between scenes could affect the enjoyability of the game. The evaluation scene can also be further developed by adding parallax mapping and by developing different modes that set certain values so that different conditions could be tested out. These can be for example different speeds, accelerations and different features that would try to reduce motion sickness. This would allow the scene to be utilized in multiple different studies further down the line.

The game could also benefit from added replay value, for example by making more use of the collectables scattered throughout the game. Collecting them could allow players to unlock hidden features or rooms. Furthermore, a high score list was thought to be implemented, but was deemed not necessary enough due to the nature of the thesis and was thus left out of the final version. A multiplayer aspect would be a good addition so the game could have an added competitive and shared enjoyment value [41],[42] and in return making the game more enjoyable in a long run while also increasing the replay value.

6.3.2. Future Hardware

The participants reported that the mismatch between reality and the virtual world contributed to the negative effects and the lack of immersion, and as the scooter controller is one of the biggest contributors to those feelings, some improvements could be made. The first thing to improve should be the way the scooter is connected to the steel plate. The scooter does not lean to the left or right like the real scooter would, so some test subjects felt a mismatch between the virtual- and the real scooter decreasing the feeling of immersion. The solution could be to add a hinge that would allow the scooter to tilt to either side according to the player. This would make the movement feel smoother and more realistic, which in turn would increase immersion, as demonstrated by Berger et al. [43] The scooter controller has a brake on its back wheel so utilizing that in braking and slowing down would make sense – especially if the scooter is going to be developed more into an electric scooter. Utilizing the existing brakes would be a natural way to slow down the scooter but adding handbrakes – which are typical with electric scooters – could also prove to be a viable option.

There is evidence that vibrations would also make the user feel more immersed. [44] The vibrations of the scooter could make the user feel like they are moving which could increase the immersion in-game and reduce the negative symptoms they might develop otherwise. In addition, a fan that would imitate the effects of wind when moving could also contribute in immersion. The fan could be attached to the board and could be controlled by the game to turn on and off when scooter is moving, and the intensity could also be adjusted according to the speed of the scooter in the game.

6.3.3. Future studies

Since the focus of this study was on motion sickness, vection and nausea, the sequential studies should concentrate on the same topics. One interesting topic of research would be to study the hypothesis presented by Arns & Cerneys' pilot study [40], according to which older people are more inclined to suffer from the effects of motion sickness during a virtual reality experience. The virtual evaluation scenes could be used as is and the questionnaires would need only slight modifications. The sample size used would have to be totally different, as different age demographics form the "meat" of the study.

Other possible research topic could be to focus solely on the effects of audio ques and background music on motion sickness, as our study hinted at a link between these two aspects. The potential soothing effects of sound and music in the context of VR were a surprise, since as of writing this thesis, no conclusive knowledge was found regarding these topics. And as such, more research is needed.

Finally, the effects a custom-built controller has on different participants during virtual reality experience could be further studied. The topics of motion sickness, vection and nausea during VR are tricky – especially when considering movement – and since real-world objects have reportedly decreased the effects of these symptoms [10], a major question becomes *"how"*. For example, where is the line between objects capable of relieving these symptoms and objects making the symptoms worse. And additionally, are there objects that could induce even more surprising effects on different users when used in virtual reality environments. The research done on the field of VR is plentiful, but as the topic of immersing yourself in a virtual reality world successfully and enjoyably is enormous, much more research is needed.

7. CONCLUSION

The objective of this thesis was to develop a virtual reality title called *Janitor Run VR* while simultaneously studying the effects of motion sickness, vection, nausea and immersion. In addition to the game development, a unique scooter controller was created in order to study these phenomena in detail. The effects were studied through two different evaluation phases, where participants (n=12 in both evaluations) were asked to play the game and answer a questionnaire regarding their experience. Slight changes to the game were made between the two evaluations, and then the results of both evaluations were compared between one another.

The results seemed to indicate, that the first iteration of Janitor Run VR induced motion sickness and discomfort in majority of its users. But then after modifying the game by decreasing the speed and acceleration in movement as well as adding sound effects and background music the perceived effects of motion sickness and discomfort lessened. While the effects of these changes can be considered to be impactful, the changes itself were quite minor. And as such, the fine tuning of VR applications seems to be a rather tricky topic.

The combined results from both evaluation results seem to indicate a link between the use of sound/music and more realistic movement speed with a more comfortable and less nauseating VR experience. But, as the sample size in both evaluations were low, the results might be skewed. In order to better understand the effects of these phenomena in the context of VR applications, further studies are required.

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9. APPENDICES

Appendix 1. The consent form for the evaluation

Appendix 2. Evaluation questionnaire for phase one

Appendix 3. Evaluation questionnaire for phase two

Appendix 4. Results for evaluation phase one

Appendix 5. Results for evaluation phase two

Appendix 1. The consent form for the evaluation

INFORMED CONSENT FORM FOR PEOPLE TAKING PART IN JANITOR RUN VR EVALUATION STUDY

Information about the study: Students from the Faculty of Information Technology and Electrical Engineering as well as a student from the Faculty of Technology in the University of Oulu conduct research for the course 521041A Applied Computing Project. The project focuses on motion sickness, vection and immersion in a virtual reality environment, where the participant uses a kick scooter to move around. This project is done in collaboration with the Center of Ubiquitous Computing.
Persons in charge of the research: Janitor Run VR study group: Kuisma Rautio (project manager), Olli Törrönen and Sami Rapakko. Applied Computing Project 1: Teaching Assistant Paula Alavesa. These persons will also provide additional information concerning this study.

Full name of participant ____

I hereby give my consent to participating to collecting research data of my actions in the given virtual reality environment. I also grant permission for the above-mentioned persons to store and use the data for research purposes. Before signing this consent form, I have got acquainted with the attached research description, its goals and the procedures related to collecting research data. I am aware of being able to withdraw my consent at any time by informing the people conducting the research about my wish. I acknowledge that virtual reality systems are known to make some people nauseous. As the research participant I have the right to stop the experiment at any time. I exonerate the people conducting the research from any liabilities regarding my personal health. I hereby promise to prevent any information leaks from participants already tested to untested participants before 27th of March 2019, as this may affect the future performance of untested participants in the study.

_________________ ____

Place and date Signature of the research participant

I hereby confirm that the persons conducting the research will use the data according to the good practices of research ethics and the regulations stated in the privacy protection law. The research participant will be given a copy of the consent form, signed by the researcher responsible of the research effort.

_________________ ____

Place and date Kuisma Rautio

The use, protection and storing of data: The persons listed in "Persons in charge of the research" above will be responsible for the protection, storing and use of the research data collected during this research effort. The research data will be utilized only in academic research (including theses for degrees) and teaching and they will not be used for commercial purposes. In publications and scientific presentations, the data will be used respecting the participants' privacy maintaining their anonymity. The research data may also be stored as such for longer-term use in research and teaching. In such a case, the data will be archived by the persons listed in "Persons in charge of the research" above, using appropriate archiving methods and techniques.

Appendix 2. Evaluation questionnaire for phase one.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

On a scale from 1 to 5, rate how much you agree with the following statements.

Question	**1**	**2**	**3**	**4**	**5**
1. I was able to control the events well.					
2. The environment was responsive to actions that I initiated (or performed).					
3. The interactions with the environment seemed natural.					
4. The mechanism that controlled movement through the environment felt natural.					
5. The experiences in the virtual environment seemed consistent with my real-world experiences.					
6. I felt discomfort or nausea during the virtual experience.					
7. I was able to actively survey or search the environment using vision.					
8. I was able to move well in the virtual environment.					
9. I did not experience any delays between my actions and my expected outcomes.					
10. I adjusted quickly to the virtual environment experience.					
11. I felt proficient in moving and interacting with the virtual environment at the end of the experience.					
12. I was involved in the experimental task to the extent that I lost track of time.					

Did you have any problems with the movement? If you did, explain in your own words what these problems were.

Did the virtual environment feel immersive or not? What things contributed to this feeling? *(for example, if your immersion broke during gameplay, what caused it)*

Did you feel any nausea or discomfort during the session? If you did, when did these feelings emerge? What do you think contributed to these feelings?

Appendix 3. Evaluation questionnaire for phase two.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

On a scale from 1 to 5, rate how much you agree with the following statements.

Question	**1**	**2**	**3**	**4**	**5**
1. I was able to control the events well.					
2. The environment was responsive to actions that I initiated (or performed).					
3. The interactions with the environment seemed natural.					
4. The moving speed in the virtual environment felt natural.					
5. The virtually recreated university was modelled well.					
6. I felt discomfort or nausea during the virtual experience.					
7. I was able to actively survey or search the environment using vision.					
8. I was able to move well in the virtual environment.					
9. I did not experience any delays between my actions and my expected outcomes.					
10. I adjusted quickly to the virtual environment experience.					
11. I enjoyed the virtual environment experience.					
12. While playing I lost the track of time because of the experience.					
13. If given the chance, I would like to try the virtual environment experience again.					

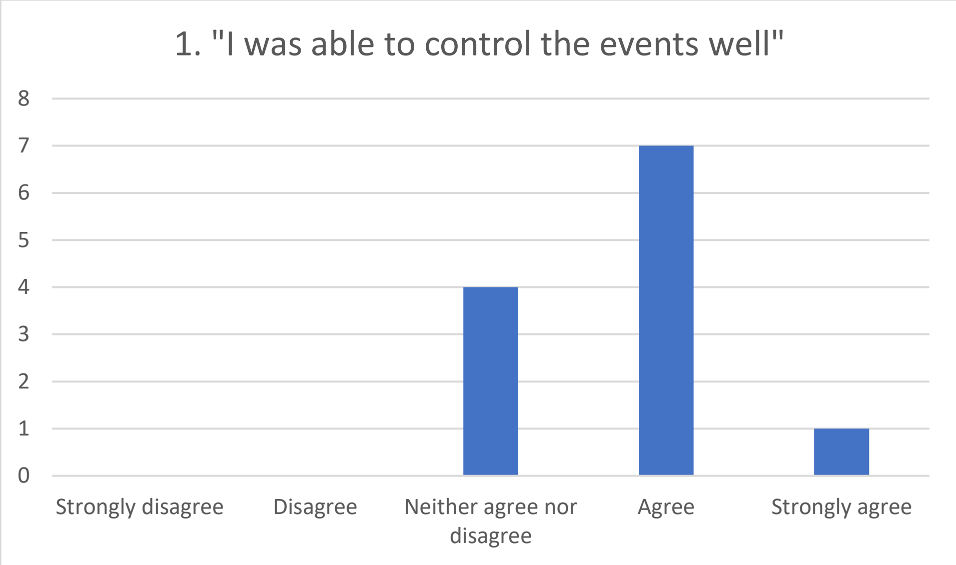
Did you enjoy the experience? What aspects of the virtual reality experience contributed to this feeling?

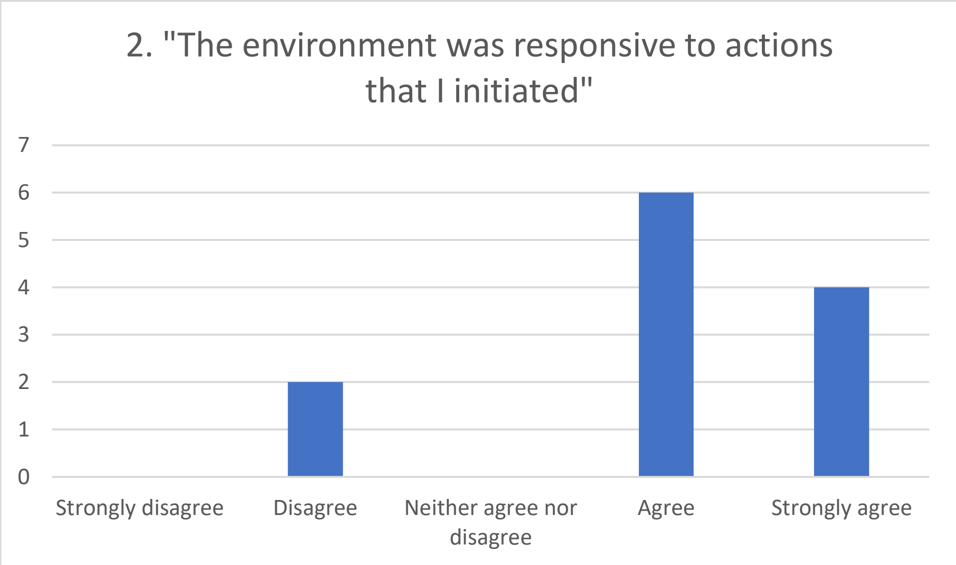
Did the virtual environment feel immersive or not? What things contributed to this feeling? *(for example, if your immersion broke during gameplay, what caused it)*

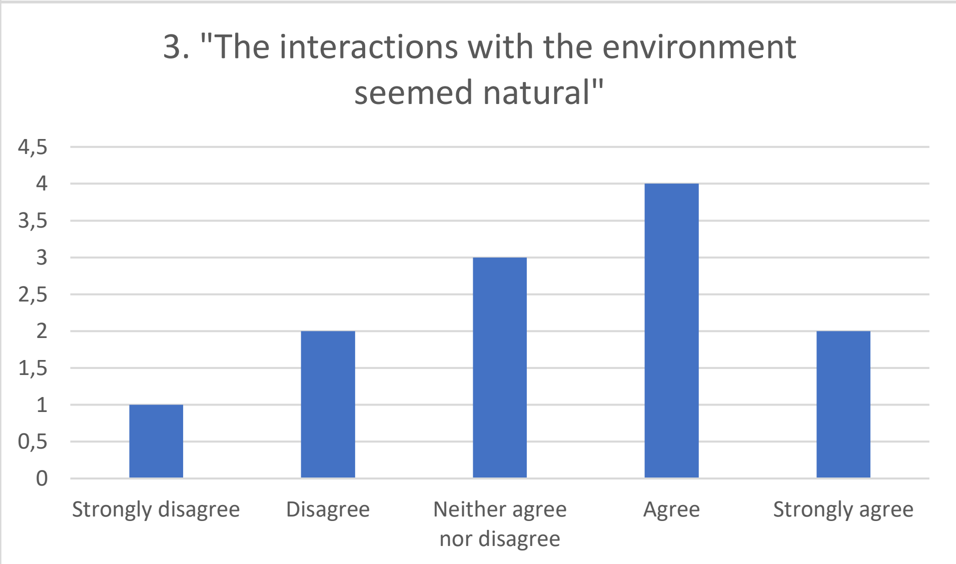
Did you feel any nausea or discomfort during the session? If you did, when did these feelings emerge? What do you think contributed to these feelings?

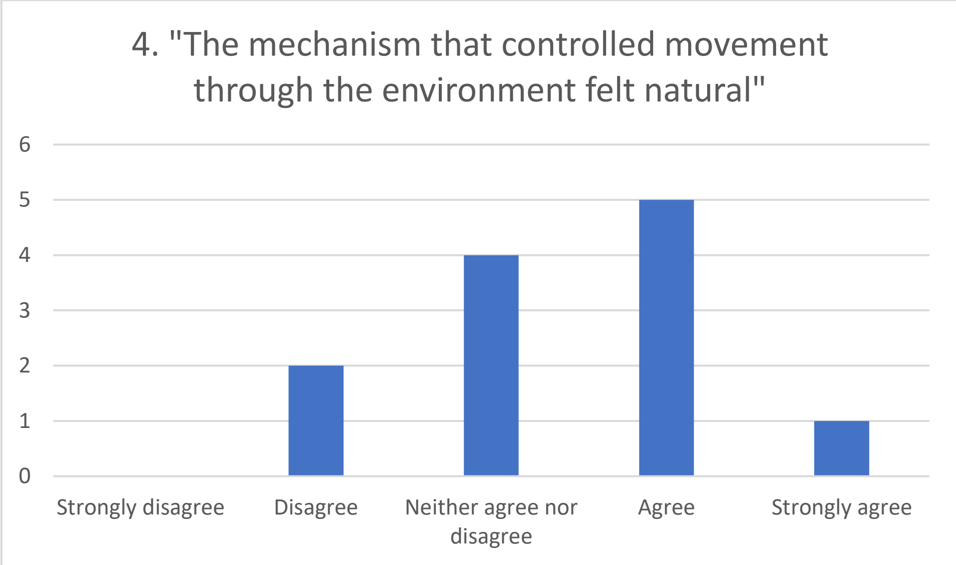
When you think back to the experience, do you think of the virtual environment more as *images that you saw* or more as *somewhere that you visited?*

Appendix 4. Results for evaluation phase one.








4. "The mechanism that controlled movement through the environment felt natural"
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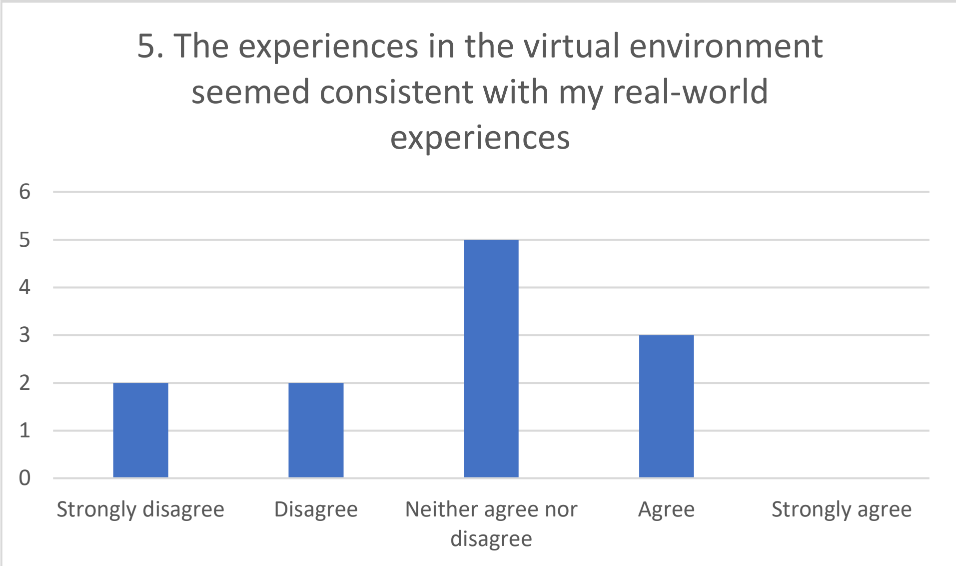
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree


5. The experiences in the virtual environment seemed consistent with my real-world experiences
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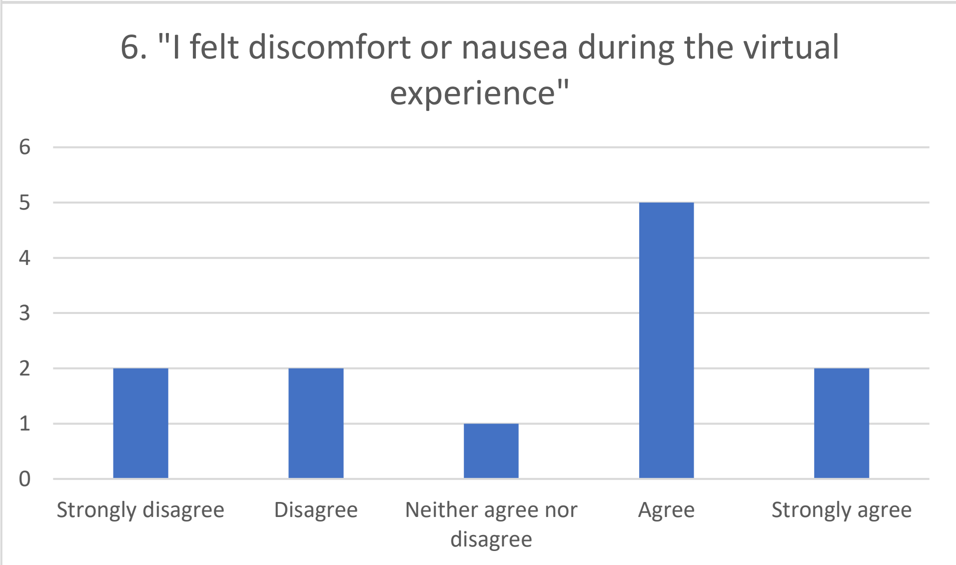
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree


6. "I felt discomfort or nausea during the virtual experience"
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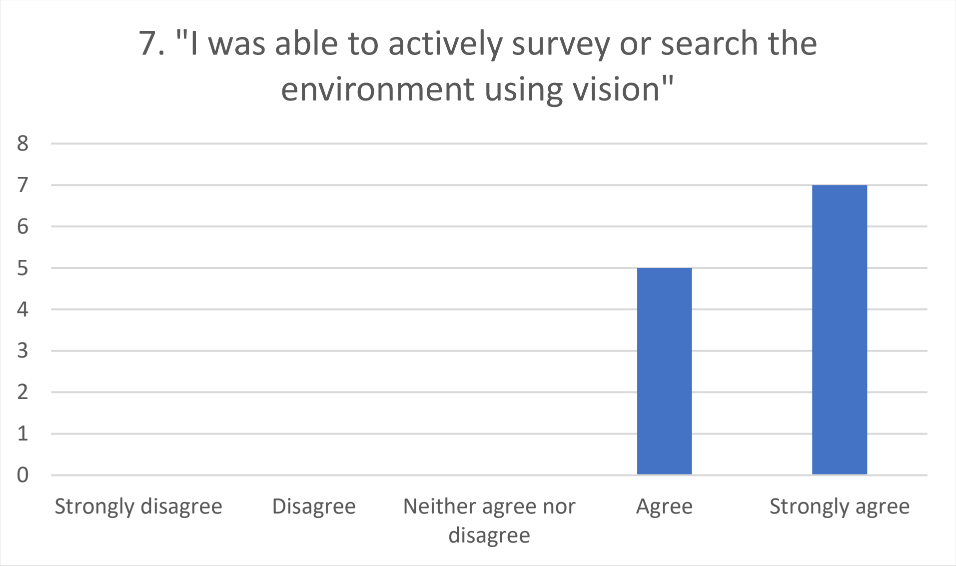
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree


7. "I was able to actively survey or search the environment using vision"
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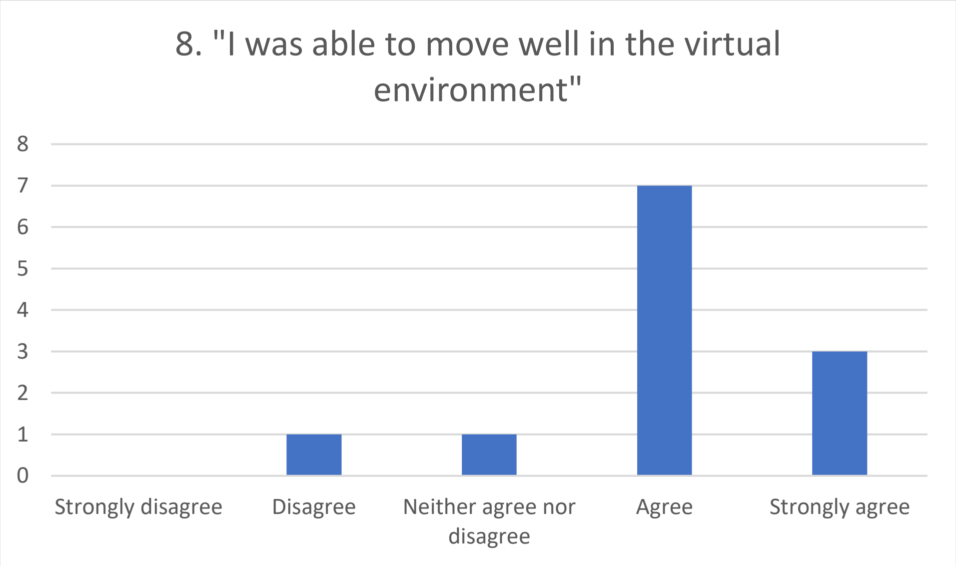
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree


8. "I was able to move well in the virtual environment"
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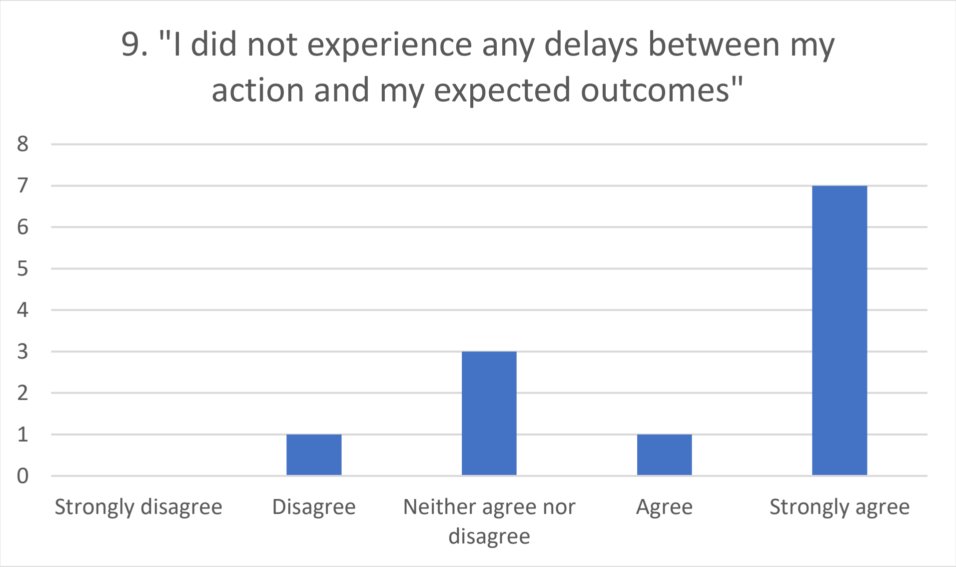
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree


9. "I did not experience any delays between my action and my expected outcomes"
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Strongly disagree
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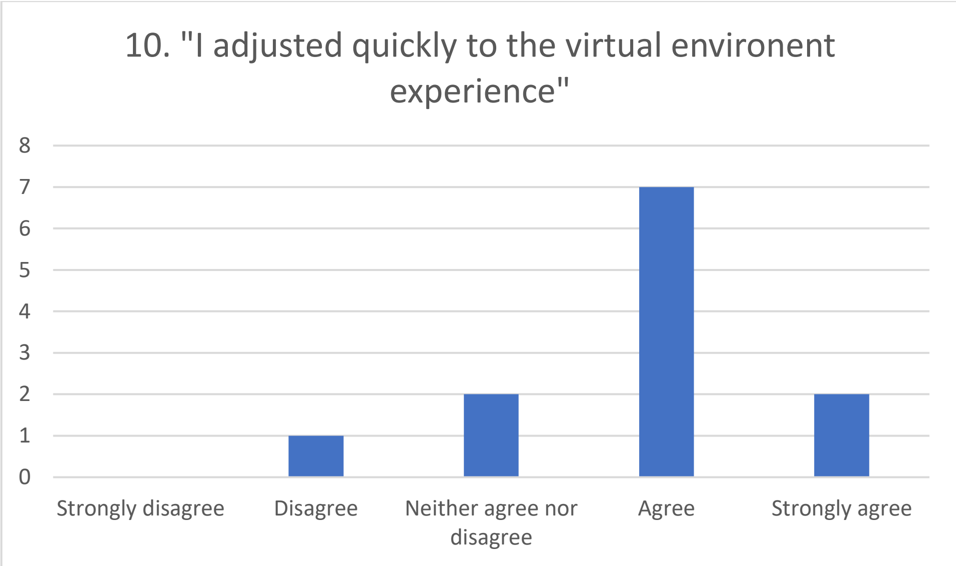
Neither agree nor disagree
Agree
Strongly agree


10. "I adjusted quickly to the virtual environent experience"
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Strongly disagree
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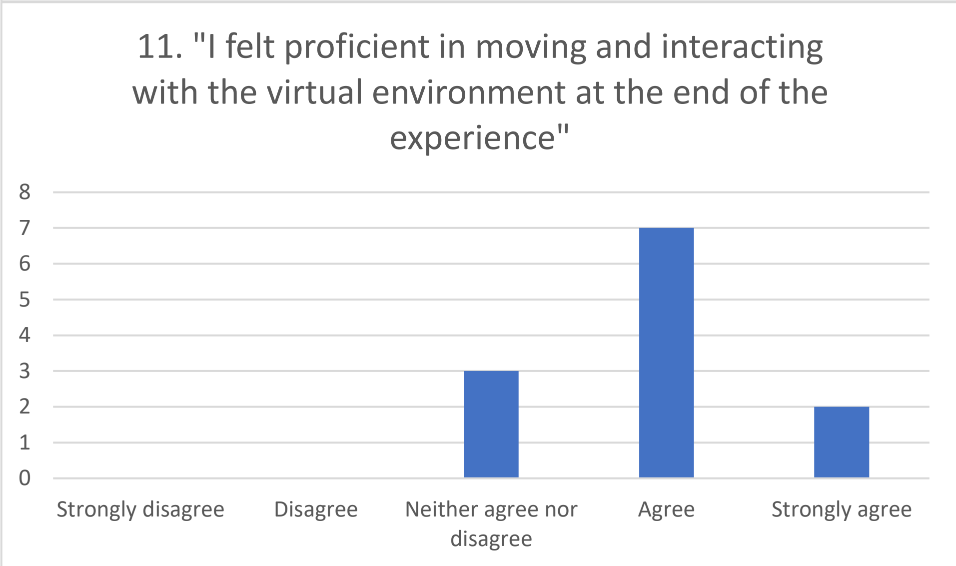
Agree
Strongly agree


11. "I felt proficient in moving and interacting with the virtual environment at the end of the experience"
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Strongly disagree
Disagree
Neither agree nor disagree
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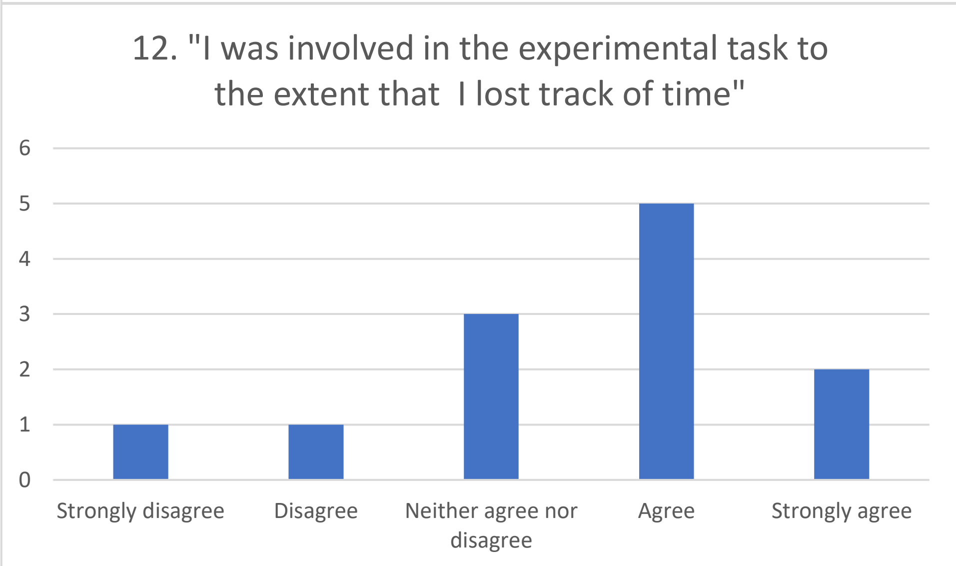
Strongly agree


12. "I was involved in the experimental task to the extent that I lost track of time"
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Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree

Answers to the open questions

Did you have any problems with the movement? If you did, explain in your own words that these problems were.

- Nopeuden säätely on vaikeaa verrattuna oikeaan tilanteeseen. Myös normaalisti tottunut kallistamaan kääntyessä, mitä ei tarvinnut tehdä.
- Tasapainolauta tuntui vastaavan pienellä viiveellä, ohjaustanko sen sijaan tuntui hyvältä.
- The acceleration did not feel consistent and I lost balance couple of times because I thought I would fall.
- Olin hieman epävarma siitä, paljonko vauhti kasvoi tietyn mittaisella painalluksella. ”Potkiminen” tuntuisi luonnollisemmalta, mutta ei antanut kovin hyvää vastetta.
- Laudan ”polkeminen” toimi heikosti, kuten oli oletettu. Nopeuden säätely painelemalla lautaa puolestaan oli helppo oppia ja tuntui jopa intuitiivisemmalta kuin polkeminen.
- It speeds up too fast. And [according to?] my experiences it is not like it’s in a real world. So something in these feels unnatural.
- Kiihdyttäminen ja hidastaminen/pysähtyminen oli aluksi hieman hankalaa, mutta siihen tottui hyvin nopeasti.
- Movement felt a bit clunky and these was a disconnect between the board moving in-game and me pressing the button. Tapping the button with my foot helped with the controls (instead of holding it down).
- Kiihtyvyyden ja jarrutuksen hallinta oli aluksi vaikeaa, mutta helpottui ajan myötä.
- Takaperin meneminen tuntui huisin aidolta etuperin kulkemisen jälkeen! Ehkä kosketuslaudan ”tarkkuutta” olisin kaivannut vähän enemmän.
- Oma tasapainoa, nopeuden arviointi vaati oppimista.
- Oli yllättävän luontevaa liikkua laudalla vaikkei ollut kokemusta.

Did the virtual environment feel immersive or not? What things contributed to this feeling? (*for example, if your immersion broke during the gameplay, what caused it)*

- Jos tarkoitetaan virtuaalimaailman syvyyttä, niin tuntui todelliselta. Kauas katsominen tuntui luonnolliselta.
- ”Immersio” rikkoutui kääntyessä, sillä potkulauta ei kallistunut, kuten se tekisi oikeassa tilanteessa.
- The acceleration, game object, collisions and rotation around z-axis broke the immersion. Overall movement was quite good though.
- Ympäristö tuntui immersiiviseltä. Kovan käännöksen aiheuttama laudalta putoaminen särki immersion hieman.
- Kokemus oli yllättävän aidon tuntuinen. Potkulaudan ohjaaminen tuntui helpolta. Tasapainin horjuminen lisäsi immersiota.
- Yes. It just felt like it is all around me. And the feeling of balance during movement played a big role in immersion.

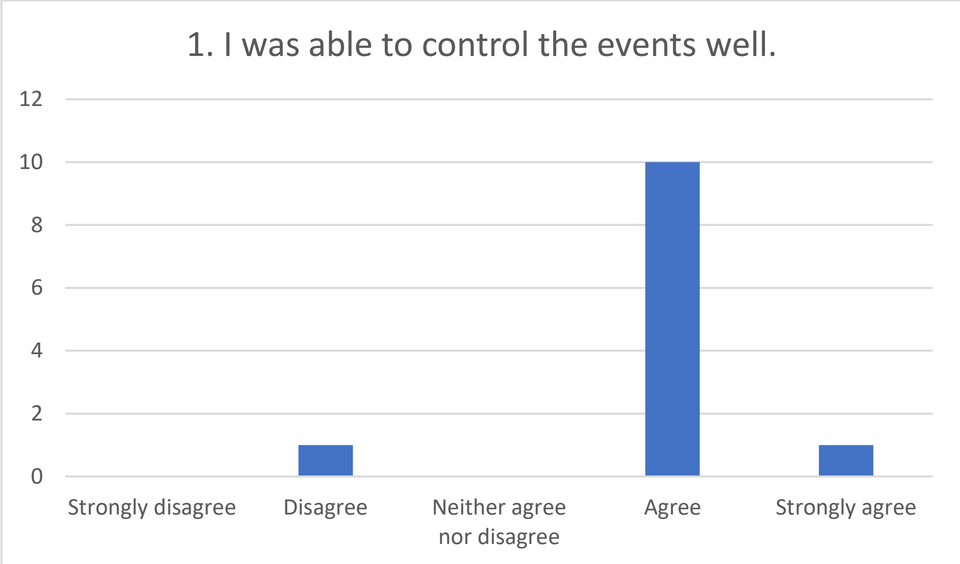
- Joo. En tuntenut mitään viivettä pelissä, ja potkulaudan fyysinen olemassaolo sai minut tuntemaan niin kuin olisin oikeasti ajanut (moottorilla varustetulla) potkulaudalla.
- Environment felt immersive.
- Kokemus oli todella immersiivinen eikä immersio katkennut kertaakaan.
- Välillä pakitus pitkän kiihdytyksen jälkeen käynnistyi vähän liian hitaasti, vika saattoi toki olla myös mun jaloissa.
- Jos alkoi itse horjumaan, se muistutti että mittasuhteet on erilaiset. Myös nopeuden portaittaneisuus ei ollut luontevaa aluksi.
- Hyvin uppoutui, ei häirinnyt mikään.

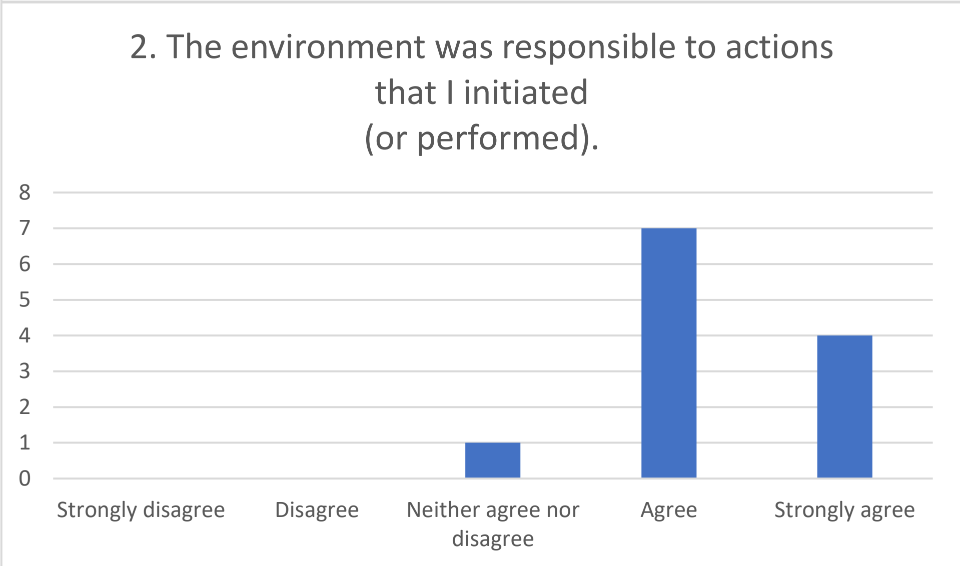
Did you feel any nausea or discomfort during the session? If you did, when did these feelings emerge? What do you think contributed to these feelings?

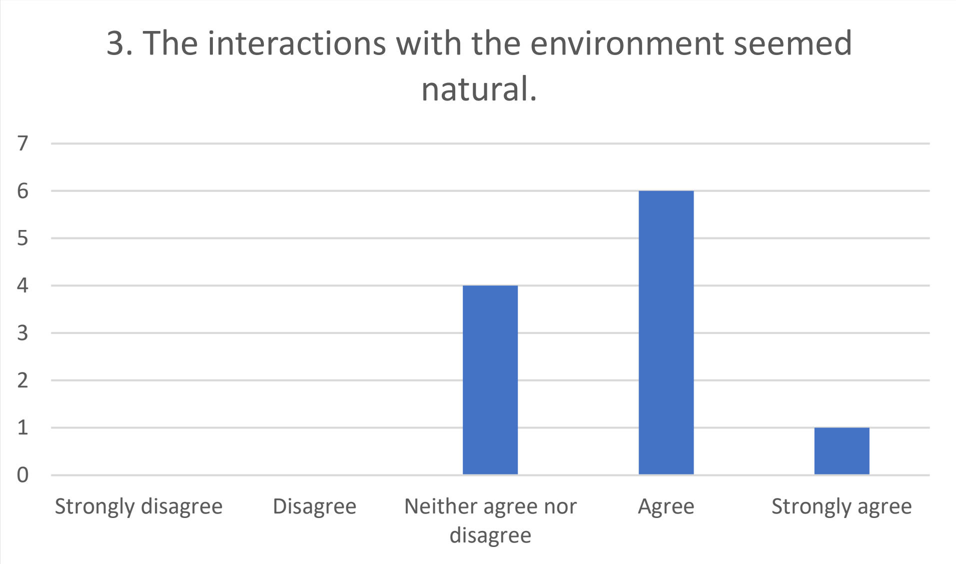
- Kääntyessä alkoi tasapaino heittää ja täten hieman huimata, mutta vain käännösten aikana. Veikkaan johtuvan kääntymisestä ja luonnollisesta kallistumisesta, jota ei saa luonnollisesti korjata silmien ja näön kautta, vaan vasta kun aivot tajuavat, että kaadut.
- Pientä huimausta kääntyessä, muuten ei liiemmin.
- I felt some in the beginning first time I hit a wall, because I thought the collision would occur differently. (more powerful)
- Tunsin kohtuullisen voimakasta pahoinvointia. Suurin syy on se, että käännyttäessä ei tunnu g-voimia sivuille päin. Pahoinvointia esiintyi erityisesti kääntyessä. Äänimaailman lisääminen (pyörien ääni, äänen kasvaminen vauhdin myötä) saattaisi vähentää pahoinvointia.
- Vauhdin äkillinen hidastuminen aiheutti hieman pahoinvointia. Samanlainen tilanne, jossa normaalistikin kokisin matkapahoinvointia.
- No, the only thing I was not fully comfortable with was the speed. In the beginning
- Erittäin lievää alussa, kun en osannut vielä pysähtyä ja putosin laudalta, mutta luulen että se johtui vain immersiosta.
- At the beginning of the experience I felt nauseated and almost fell over, but the nausea lessened over time. Unfamiliarity with the control and balancing on the board.
- Nopeissa käännöksissä tuntui huojumista sivuille ja voisin kuvitella oikean elämän kaatumisenkin tapahtuvan helposti, varsinkin kokemattomilla pelaajilla.
- Takaperin huimasi! Mut se oli kivaa ja immersiivistä!
- Ensimmäisen 20 sekunnin jälkeen ja jatkuu kokeilun loputtua. Johtuu varmaan omasta taipumuksesta voida vastaavissa tilanteissa pahoin.
- Jos olisin mennyt pidempään, olisi voinut olla pahoinvointia. Tässä ajassa ei juurikaan.

Appendix 5. Results for evaluation phase two.

ANSWERS TO THE QUESTIONNAIRE – PHASE 2






3. The interactions with the environment seemed natural.
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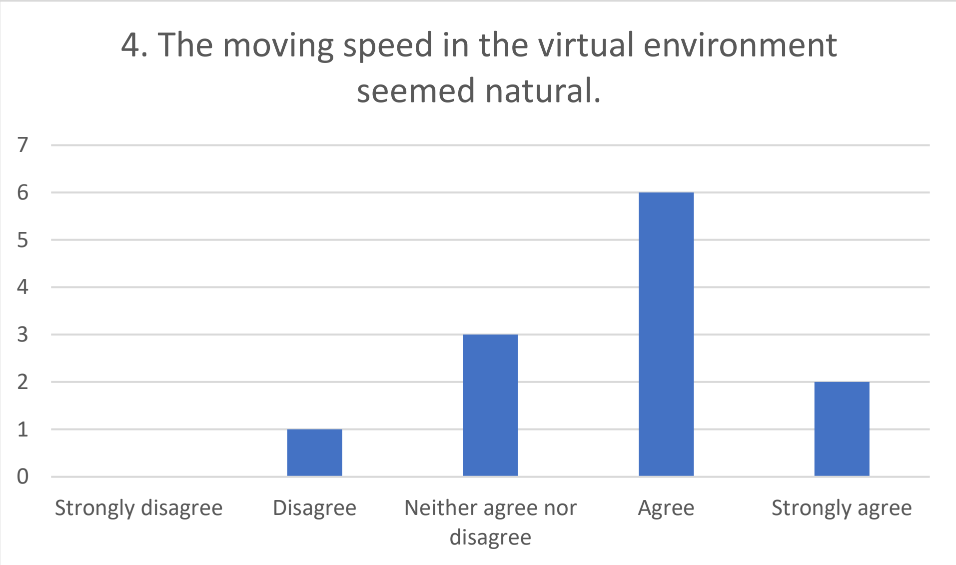
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree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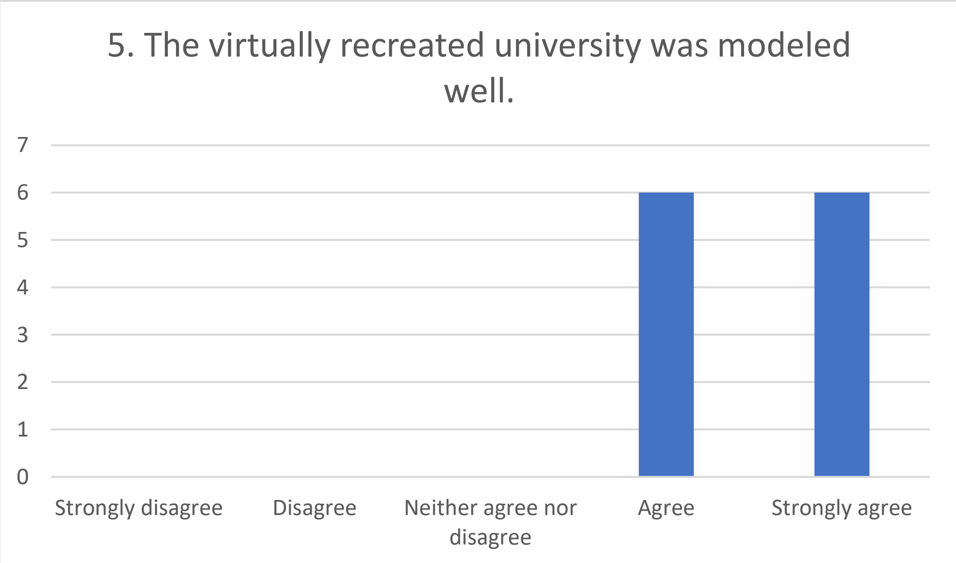
5. The virtually recreated university was modeled well.
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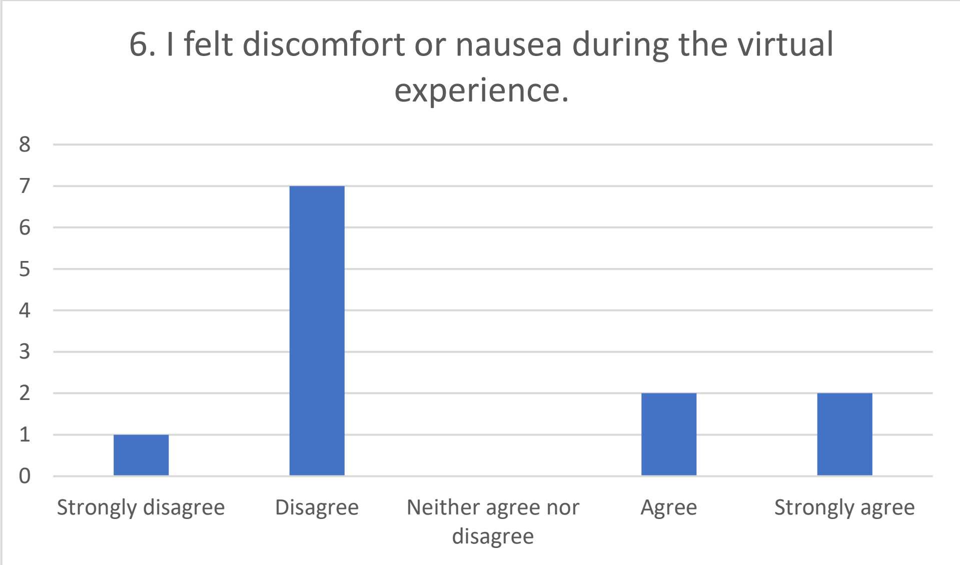
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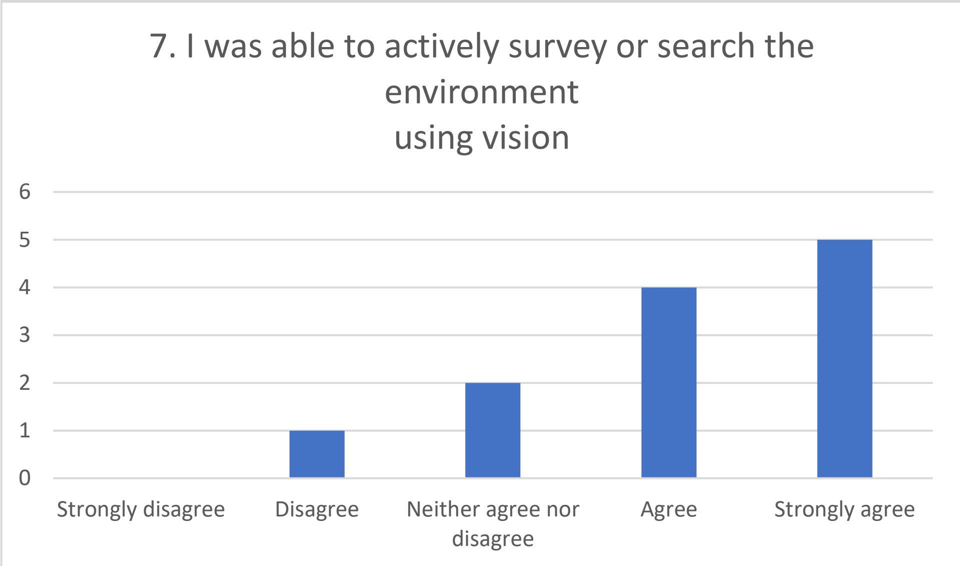
7. I was able to actively survey or search the environment
using vision
6
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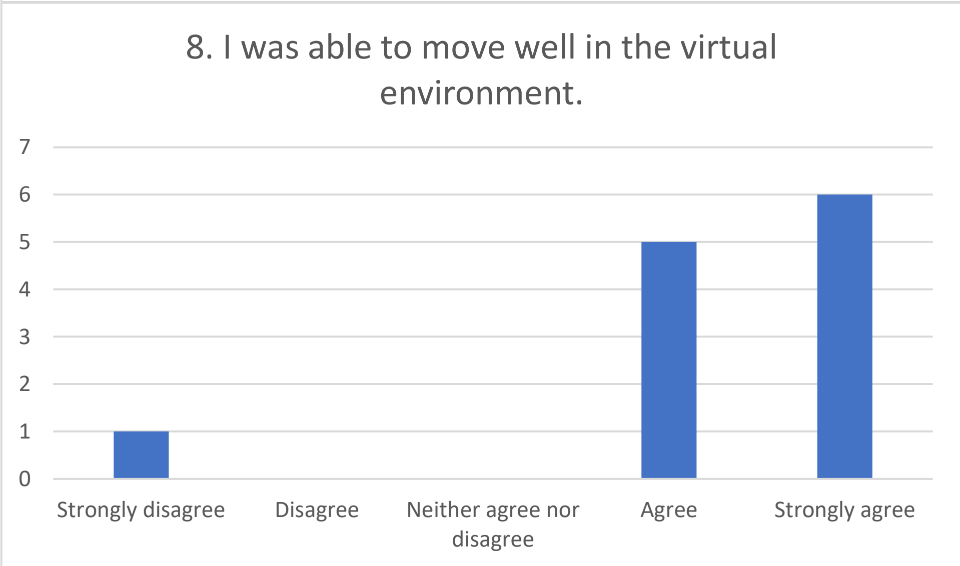
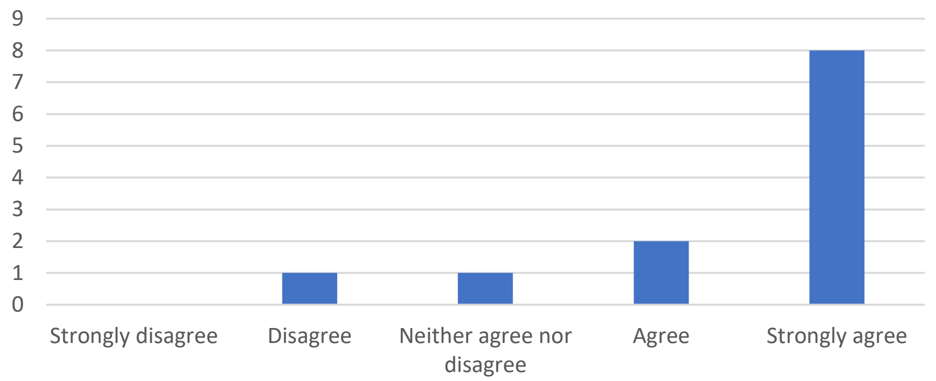
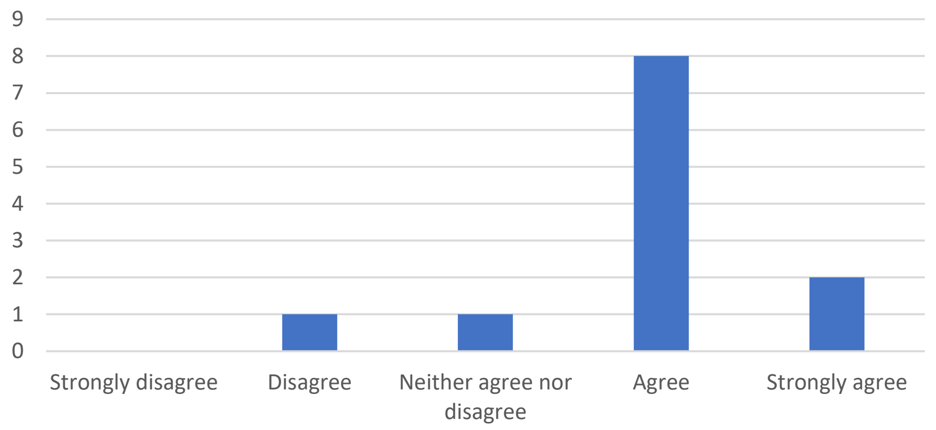
4
3
2
1
0
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree


8. I was able to move well in the virtual environment.
7
6
5
4
3
2
1
0
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree

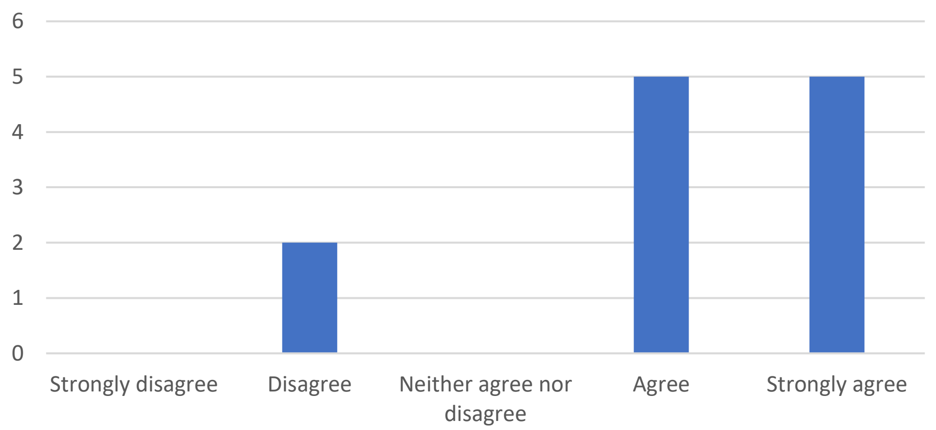
9. I did not experience any delays between my actions and my expected outcomes.

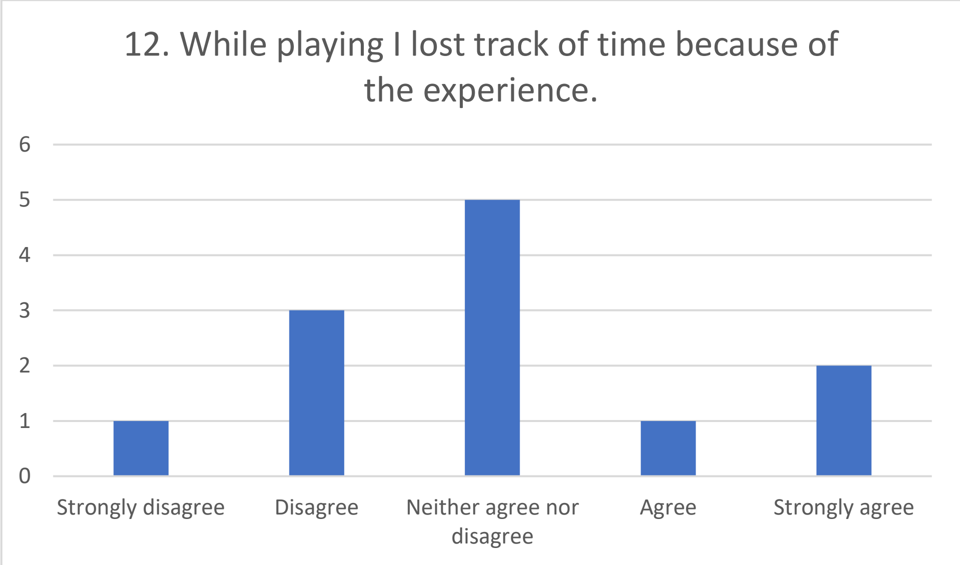


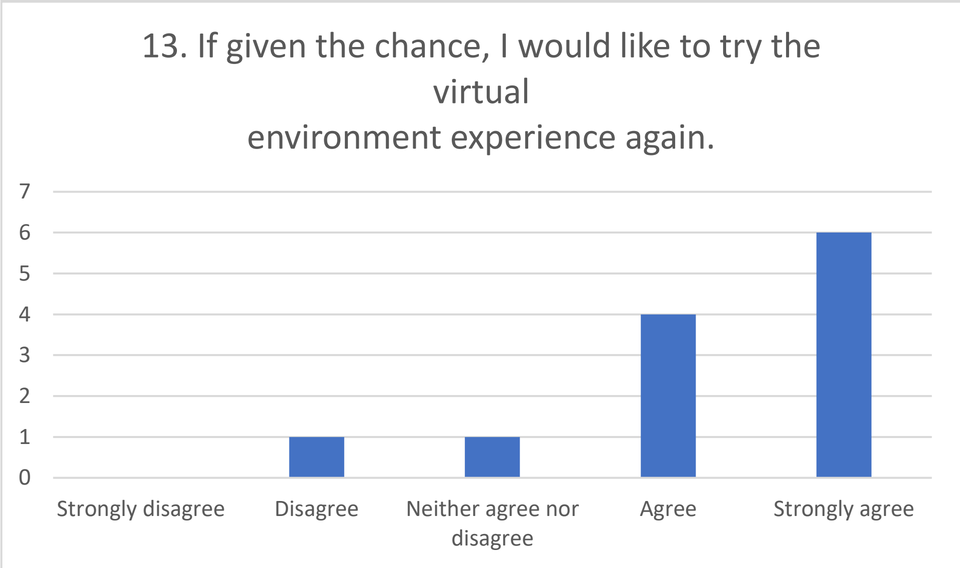
10. I adjusted quickly to the virtual environment experience.



11. I enjoyed the virtual experience environment experience.




12. While playing I lost track of time because of the experience.
6
5
4
3
2
1
0
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree


13. If given the chance, I would like to try the virtual
environment experience again.
7
6
5
4
3
2
1
0
Strongly disagree
Disagree
Neither agree nor disagree
Agree
Strongly agree

ANSWERS TO OPEN QUESTIONS – PHASE 2

Did you enjoy the experience? What aspects of the virtual reality experience contributed to this feeling?

1. I enjoyed the experience. I do not have much previous experience with VR, so it was interesting to try. It was cool to see the university in VR form and fun to cruise around it. The music added to the experience.
2. Kokemus oli hyvä enimmäkseen immersion ansiosta, sillä kokemus tuntui suhteellisen aidolta.
3. I felt dizziness occasionally. It was OK.
4. I enjoyed the experience
    a. scooter
    b. the headset
5. Nautin kyllä kokemuksesta. Etenkin potkulauta oli ohjauskeinona sellainen, mitä en, mitä en ollut ennen kokeillut ja siksi hyvin mielenkiintoinen kokemus.
6. It was nice. I liked that the university was kind of the same as it is but there were also a lot of stuff which were different.
7. Liikkuminen tuntui vaivattomalta ja nopeuden tunne sai adrenaliinin virtaamaan.
8. Oli mukavaa, potkulaudalla ohjaaminen VR:ssä oli uutta ja samalla siten ihan hauskaa.
9. Potkuttelu tuntui melko, jopa yllättävän, luonnolliselta. Harjoituskenttä pakotti tekemään paljon nopeita kiihdytyksiä ja käännöksiä mikä aiheutti pahoinvointia.
10. Pidin kokemuksesta. Jännä päästä testaamaan vr-laitteita. Erilainen ja uudenlainen kuin esim. normaali pc-pelaaminen.
11. Pidin demosta, potkulauta tuntui hyvin aidolta.
12. Nautin kyllä, erityisesti alussa VR huijasi hyvin aivoja, eikä kaatuminen ollut kaukana. Potkulauta olio mielestäni hauska oivallus VR:ään.

Did the virtual environment feel immersive or not? What things contributed to this feeling? (*for example, if your immersion broke during gameplay, what caused it*)

1. The environment felt immersive. Moving around in it felt natural and the crash sound effects when bumping into walls made me want to try to avoid hitting them. I still felt like I was standing still

playing a game, in part because of the pixel-y graphics that I saw sometimes. (maybe my eyes didn't adjust yet.)

2. Potkulauta on hyvin tehty ja tottelee ohjausta mielestäni hyvin. Peruuttaminen oli ehkä hieman hidasta ja yhdessä kohtaa tuntui, että tangon asento ei täysin vastannut pelissä olevaa asentoa.
3. Not so much. Over all experience.
4. It was winter outside ☹. I discovered I can just leave my foot on the wii-board (and I felt it because I'm lazy). By default that should not possible (IMO)
5. Kyllä. Se, että ohjaus tuntui luonnolliselta ja että potkulauta oli mallinnettu hyvin virtuaalitilaan, paransivat kokemuksen todentuntuisuutta. Myös yliopiston hyvä 3D-malli lisäsi tätä kokemusta.
6. Yes, exactly because it is planned so close to reality.
7. Oli samanlainen fiilis, kun pelaisi autopeliä ja halusi päästä vain lujempaa.
8. Potkulaudan nopeus tuntui nopeammalta kuin mitä se olisi oikeassa elämässä, muuten tuntui että oli ”immersive”.
9. Ympäristö tuntui hyvin immersiiviseltä. Potkulautaohjain toimi hyvin. Teki mieli väistellä seiniä tosissaan.
10. Erittäin mukaansatempaava ja hyvin yliopiston väyläksi tunnistettu.
11. Kyllä tuntui, pelissä oli helppo edetä ja peli oli hauska.
12. Kyllä tuntui mukaansatempaavalta. Erityisesti se, kun yhdisti tilat Oulun yliopistoon ja se lisäsi halua seikkailla siellä.

Did you feel any nausea or discomfort during the session? If you did, when did these feelings emerge? What do you think contributed to these feelings?

1. I did not feel nausea or discomfort. I do feel motion sickness occasionally when playing first-person games, but not in this case. Maybe I would have felt sick if I had played for a longer time?
2. Ehkä ihan vähän pahoinvointia pelin loppupuolella lähinnä kääntymisestä tulleesta epätasapainon tunteesta.
3. Yes. Mostly on the training part and in the game when I had to turn or go backward.
4. No, but after the session it feels a bit funny.
5. En tuntenut varsinaista pahoinvointia, mutta jyrkissä käännöksissä yritin kompensoida käännöksiä liikkumalla, mikä oli hieman

hämmentävää. Tähän kokemukseen voi vaikuttaa aikaisempi runsas kokemus virtuaalitodellisuudesta.
6. No.
7. Ensiksi kyllä, ajan kanssa se alkoi helpottaa. Tasapaino oli ehkä isoin tekijä, peli ei rekisteröinyt tasapainon heittelyä ja kuva pysyi paikallaan.
8. Aivan aluksi kun opettelin liikkumaan laudalla tasapaino horjui: liikkuessa horjui eteenpäin ja käännöksissä, etenkin nopeissa horjui sivuille, ei pahoinvointia.
9. Tämä oli yksi eniten pahoinvointia aiheuttaneista VR-kokemuksista mitä olen kokeillut. Veikkaan, että alun harjoituskenttä oli suurempi aiheuttaja pahoinvoinnille kuin varsinainen kampus.
10. Ei mitään merkittäviä epämiellyttävyyksiä. Lasien ja kuulokkeiden istuttavuus päähän miellyttävä.
11. Alussa tasapaino tuntui hieman omituiselta.
12. Ei ilmennyt pahoinvointia.

When you think back to the experience, do you think of the virtual environment more as *images that you saw* or more as *somewhere that you visited?*

1. Somewhere that I visited (by seeing images of it)
2. Enemmän paikkana, jossa kävin.
3. More as images.
4. Yes. (I don’t know).
5. Kuvia, jotka näin.
6. The place itself.
7. Enempi välimaastoa, verrattavissa normaaliin tietokonepeliin, johon uppoutuu ja unohtaa fyysisen olemassa olon.
8. Paikalta, jossa kävin.
9. Enemmän paikka, jossa vierailin.
10. Mahdollistaa todenmukaisemman vierailun kuin pelkillä kuvilla.
11. Enemmänkin paikkana, jossa on käynyt.
12. Enemmän paikkana, jossa kävin.